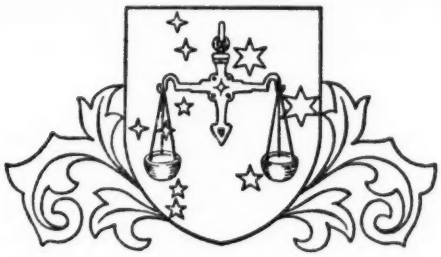
1831  1951

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Sir John Russell, O.B.E., F.R.S. (1949)
Sir Harold Hartley, K.C.V.O., C.B.E., M.C., F.R.S. (1950; Chairman of Council, 1951).

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ASSOCIATION AFFAIRS

The President

On January 1, 1951, the Presidency of the Association passed from Sir Harold Hartley to H.R.H. the Duke of Edinburgh who was then on duty in the Mediterranean and sent the following message of greeting to the Association :

> It gives me great pleasure to accept the appointment of President of the British Association for 1951.
>
> I consider it to be a very great honour and I shall do all in my power to further the interests of the Association in the coming year.
>
> I regret that I shall still be with the Mediterranean Fleet for the opening stages of my term of office, but I am looking forward to the Annual Meeting in Edinburgh in August. Until then Sir Harold Hartley has kindly agreed to act for me.
>
> PHILIP.

This message was read at Burlington House on January 5 before a general assembly of the members of the Committees of Sections and a loyal acknowledgment and reply was telegraphed to the President.

The meeting on January 5 was the occasion when the Committees of Sections assembled to determine the outline of the programme for the Annual Meeting. Sir Harold Hartley was unfortunately prevented from being present. He sent a message in which he warmly welcomed H.R.H. the Duke of Edinburgh as President and said he regarded the Duke's acceptance of the office as a most happy omen for the success of the Association's Meeting in the year of the Festival of Britain. Sir Harold also expressed his thanks for the support, unfailing kindness and consideration of all his colleagues in his own year of office as President.

The Edinburgh Meeting

The Annual Meeting for 1951 will be held in Edinburgh during the period August 8–15 and a Preliminary Programme will be published in the week after Easter. The manifold attractions of Edinburgh are well known and an enthusiastic local organisation has been at work for many months in preparation for this sixth meeting of the Association in Scotland's hospitable capital. At the Council's request it has been arranged that a proportion of the scientific programme will deal with the contributions of British Science to the progress of civilisation during the past century, so there will be much in keeping with the objects of the Festival of Britain, but not to the exclusion of topical reviews and intersectional discussions which form the traditional pattern of the programme of an Annual Meeting. The Edinburgh International Festival of Music and Drama will open four days after the Meeting ends and members of the Association may find it possible to attend both.

Future Meetings

The meeting in 1952 will be held in Belfast (Sept. 3–10) where the Association last met in 1902. The Secretariat would welcome from members notification, however provisional, of intention to be present so that adequate arrangements can be made for cross-channel transport and for accommodation. The meeting in 1953 will be held in Liverpool.

Down House

In September last the Council reported to the General Committee that some progress had been made with a proposal that Down House, which is maintained by the Association as a national memorial to Charles Darwin, might become a centre for short residential courses in the natural sciences. Since then there have been further discussions between officers of the Association, the Kent County Council and the Extra-Mural Delegacy of the University of Oxford and there are good prospects of arranging triple responsibility

for developments which would provide a living memorial to Darwin. Meanwhile the House and grounds are being faithfully maintained and visitors will continue to be welcomed. The House is sixteen miles by road from London Bridge and four miles from Orpington Station. The village of Downe can also be reached by No. 146 omnibus, from Bromley South Railway Station (twenty minutes' run from Victoria Station). The Association is lending Darwiniana from the Down House collection for exhibition in the Dome of Discovery in the Festival of Britain South Bank Exhibition.

Birmingham Meeting : Postscripts

In the account of the Birmingham meeting which appeared in the last number of *The Advancement of Science* (p. 275) the date of the previous meeting there was wrongly given as 1914. It should have been 1913.

Since the meeting, authors of papers read to the Sections have been supplying to the office references to publication of their papers in other journals. A complete list of references received to date is published in this number (pp. 459–462). It is of interest to note that *Nature* has published reports of 26 of the 36 main discussions and groups of papers and this opportunity is taken to acknowledge the service rendered by the editors and publishers of that journal to the Association. The only other comparable performance is in the columns of *Engineering*, whose editor has for many years published practically every paper read to Section G. He has also recorded and frequently published what was best in impromptu discussion.

Members who were specially interested in the Evening Discourses at Birmingham might like to know that the substance of Dr. Lovell's discourse on 'The New Science of Radio Astronomy' was published in *Nature* (Jan. 20, 1951) ; and that Dr. Thorpe is publishing in *The Bulletin of Animal Behaviour* No. 9 (1951), a full English translation of Professor Von Frisch's 'Recent Advances in the Study of the Orientation of the Honey Bee.' This will have sections dealing with solved and unsolved problems of bee language ; the polarisation of light from the sky as an orientation factor in the dances of the honey bee ; the sun as a compass in the life of honey bees.

The Association and Safety Matches

At Birmingham there were several references to one of the interesting unrecorded incidents in the history of the Association, and as the story became a little distorted on being passed from one to another it may be as well to set down what appear to be facts. At the Association's meeting in Birmingham in 1849 Professor Schroetter of Vienna read a paper 'On the Allotropic Condition of Phosphorus' (*Ann. Rept, 1849, Trans. 42*), in which he described, with demonstration, the transformation of yellow phosphorus to red under the action of light and heat. Mr. Arthur Albright, manufacturer of yellow phosphorus, with whose family Professor Schroetter stayed during the meeting, was interested in the relatively harmless red phosphorus, experimented with it and was eventually able to put its manufacture on a commercial basis. He exhibited specimens at the 1851 Exhibition where it attracted the attention of the brothers Lundström, match-makers of Jonköping in Sweden. They took some back to Sweden and prepared boxes of matches, meaning to test them in a year. They were lost and rediscovered in 1855 when F. Lundström found that a match from one of the boxes, rubbed on the prepared surface, leaped into flame—'the forerunner of untold millions.'

'Endeavour' Prize Essay Competition

The publishers of the quarterly journal *Endeavour* have decided to offer again this year, in connection with the Association's meeting, prizes for essays written by authors under 25 years of age. There are four prizes of 50, 25, 10 and 5 guineas, the last being for authors under 18. The essay subjects are : A century of science in Britain ; Chromatography and its possibilities ; Biological effects of radiation ; Science and weather ; Seaweeds and their uses ; The age of the earth's crust ; Animal locomotion ; The chemistry of non-atomic explosives.

Full details of the conditions of the competition will be sent on application to the Assistant Secretary of the Association.

SIR HAROLD HARTLEY HONOURED BY THE UNIVERSITY OF BIRMINGHAM

On the occasion of the British Association's visit to Birmingham, the University honoured the President, Sir Harold Hartley, by admitting him to the Honorary Degree of Doctor of Science. The Degree was conferred by the Vice-Chancellor, Sir Raymond Priestley, at a special Degree Congregation on September 2, 1950. The following are the texts of an oration delivered by the Public Orator, Professor O. Hood Phillips, who presented the President, and of an address delivered by Sir Harold on receiving the Degree.

Professor O. Hood Phillips :

We who work where Watt and Boulton worked, and breathe the air (though in a less pure form) that Joseph Priestley breathed, have titles manifold to honour a scientist who has so well combined theory and practice. Our pleasure is doubled by the occasion, for he is President of the British Association for the Advancement of Science, now meeting in our midst ; and it is further enhanced because the honour comes to him on the eve of his birthday.

At Balliol he gained a scholarship, tutorship, fellowship, and the hand of his Master's daughter. For thirty years he lectured on physical chemistry at that college of which he is now an honorary Fellow ; writing valuable papers on chemistry and industrial research, studying deeply the history of science, and earning a Fellowship of the Royal Society.

His ideas did not remain in a gaseous state, for they crystallised into solid advice given to many public bodies. During the next fifteen years, as Vice-President and Director of Research to the London Midland and Scottish Railway, he helped to keep the wheels of transport not only turning but on the right lines. In the first world war he had advised the Army and Government on chemical warfare. His advice was equally sought in the second world war, during which he was on the Advisory Council of the Department of Scientific and Industrial Research and Chairman of its Fuel Research Board, as well as helping the Ministry of Fuel and Power and the Mines Department. His was never a policy of adding fuel to the flames, but rather of increasing economy along with efficiency. A special task was to prevent one particular Axis from being too well oiled.

Already familiar with the interrelations of railway and air services, he was chosen after the war to direct our European and Overseas Airways. Now Chairman of the Electricity Supply Research Council, he continues also to play a leading part—perhaps we may say the leading part—in the World Power Conference, for he is gravely concerned with the use man makes of his rebel powers.

So great a labour over so wide a field of public service as teacher, research worker, director of research, technical adviser and administrator, has its motive power in a warm humanity ; but it has only been rendered possible, even in a man of his ability, by working constantly at high pressure—a pressure that sometimes electrifies his colleagues. It implies a grasp of many branches of natural science. We have not yet mentioned his interest in cast iron, vitreous enamels, rubber manufacture, non-ferrous metals and the preservation of works of art. But an enumeration of all the subjects in which he has researched, advised or directed would try even the patience of the British Ass.

To describe the theme running through his very active life we need not search the Greek and Latin classics (though he would understand the reference as well as anyone present) ; nor the pages of our Warwickshire poet whose birthplace is the goal of pilgrimage to-day : for his life and work are epitomised in the title of a neighbouring exhibition—he is a model of Energy in the Service of Man.

Sir Harold Hartley :

It is not easy to express adequately my gratitude to the University and my appreciation of the great honour you have conferred on me. Of course, you were really honouring the British Association, and I am the happy and fortunate individual on whom the honour falls. So when my transitory eminence is over I

shall enjoy this dignity as a reminder of these happy and memorable days in Birmingham.

It is appropriate that speaking in this hall I should thank the University for their hospitality to the Association. There could be no better setting for our meeting than your admirably planned and grouped Departments. They have housed our Sections so well and have made so easy those migrations from one Section to another that are such a feature of the Association.

It is a special pleasure for us to be meeting here in this Jubilee year of a university which has such great scientific traditions and achievements. I like to think of Josiah Mason and his wonderful foresight which foresaw the need for science in a great industrial community like yours.

The strength of your scientific and your engineering Departments lies in their creativeness. That can be seen in the contributions which members of your University are making in every one of our Sections and in their stories of the great work that is being done here. What changes I have seen in the past half-century! I remember one professor who seemed to think his main responsibility to the University was to prevent any risk of damage to its apparatus by its use by students. So scrupulous was he in locking it up that his lectures always started half an hour late.

And what advantages you enjoy in having your science set in a university, in a microcosm of the world! Alexis Carrel in *Man the Unknown* said that the specialist was the greatest danger of the modern world, but, as he admitted, an unavoidable danger. The remedy lies in a synthesis of specialists, and that your University supplies in the full life it opens up in the fellowship of your undergraduates and the possibilities if offers for the cross-fertilisation of one subject by another. The friendships made here that persist in after life mean so much to the integration of our modern society.

And then there are the opportunities that a university provides for its undergraduates to find their real interests and to migrate to the subject of their choice, as Dr. Flugel told us he had done in his admirable presidential address to Section J. I was grateful to him for recalling that I was not one of those who tried to dissuade him from his change of plans. I remember how my own undergraduate friendship with a historian — a great American historian, Roger Merriman— took me to Harvard to meet Theodore Richards, to whom I owe the inspiration of my scientific work.

But, Mr. Vice-Chancellor, the creativeness of your University is not limited to science. I recall, for instance, the great creative work in literature of Ernest de Selincourt. And your University owes a great debt to the catholicity of tastes and interests of its three vice-chancellors. I think of my old friend, Charles Grant Robertson: how much you owe to his persuasive conversation, his sympathy and kindness and his thirst for knowledge! I remember being called on to explain to him the advantages of polyphase alternating current.

You did not hesitate to introduce technology into the studies of your University. And why not, now that it is no longer based on the empiricism of utility but has its foundations firmly rooted in fundamental science?

Yours is a civic university set in the midst of a great industrial community, set on a hill with your great Tower as a perpetual reminder to all of your existence. You owe so much to the generosity of your citizens, you are a part of their community, and Birmingham is a great example of what the relations of town and gown should be.

This meeting of the Association has shown clearly the strength of British fundamental work in every branch of science, so there is good ground for optimism in these difficult days. In my Address I spoke of the momentum of the Elizabethan Age. To-day we see another Elizabethan reaction to stress and danger. What happier omen could there be?

And now there is the problem of the application of the great fund of research to industry, so rightly stressed as vital for this country. But its mere reiteration may earn for it some of the disrepute of the blessed word Mesopotamia. May I for a moment speak from my own experience of thirty years of the conditions in industry

that are essential for success? First I would put a sympathetic chairman, with the insight and imagination to see the part research must play in modern industry. It has been my good fortune to have served under four such chairmen. Let me name them—Sir David Milne-Watson, Lord Stamp, Lord Royden and now Lord Citrine.

Next it is essential to have someone at the policy-making level who has had actual experience of research, who understands its ways, its difficulties, its disappointments and the conditions for success : someone with the gift of choosing men with the qualities that research demands ; for success depends on the man and not on equipment for organisation, however essential these may be.

And then in every business there should be a research unit, large or small according to its size, composed of men whose task was forecast so well by Bacon in his *New Atlantis*. 'We have three,' he said, 'that bend themselves, looking into the experiments of their fellows, and cast about how to draw out of them things of use and practice for man's life and knowledge, as well for works. . . . These we call dowry-men or benefactors.'

It is the business of the dowry-men of the research unit to watch the ever-widening fields of experiment and to see how the new knowledge can be applied in their industry. But it is not their business, as Adam Smith put it, merely to observe everything and to do nothing. They must have their laboratory in which to experiment and apply that new knowledge and help to solve the difficulties of their colleagues, the technicians and engineers. And for a successful partnership with mutual confidence and understanding, engineers and technicians are needed with a thorough fundamental training, such as you give them in this university.

It is one of the main functions of our Association to win the sympathy and interest of the British people in the advance of science and in the progress that must affect their lives so much. At the moment, and let us be quite frank about it, there is much suspicion and mistrust. I must here break a lance with an old friend, the late President of the Classical Association, Lord Soulbury, who in his Address would restrict the scientist to the laboratory, the lecture room and the study.

Times have changed since Donne, preaching in old St. Paul's on 'Reason and Faith,' could say 'So by the benefit of this light of reason, they have found out Artillery, by which wars come to quicker end than heretofore, and the great expense of blood is avoided : for the numbers of men slain now, since the invention of Artillery, are much less than before when the sword was the executioner.'

To-day we are suspect, for our suspected ὕβρις, due largely, I suggest, to a recollection of the dogmatism of the Victorian scientists. There was, too, a certain arrogance in Bacon's boast when he saw man 'enlarging the bounds of human empire to the effecting of all things possible.' There was a misconception underlying his *New Atlantis* when he pictured the advance of knowledge as an almost mechanical process, ignoring the flash of inspiration that marks the great advances, and not recognising genius like Gilbert's when he saw it.

To-day, with our greater understanding, there is humility in the minds of all scientists. The further we penetrate into Nature's secrets, the more clearly we see the ever-receding frontiers of knowledge, those illimitable vistas of the unknown, the great complexities of Nature and her marvels.

And so I would leave you with the memory of some lines I learned to love from a great physician, William Osler, the words of that wise old physician of Norwich, Sir Thomas Browne, not perhaps a great scientist, but one who knew his fellow men and had watched them so often at the close of life's strange eventful journey : 'There are two books,' he said, 'from whence I collect my divinity ; besides that written one of God, another of his servant nature, that universal and public manuscript, that lies expansed unto the eyes of all ; those that never saw him in the one, have discovered him in the other. . . . Now nature is not at variance with art, nor art with nature, they being both servants of his providence ; art is the perfection of nature ; nature hath made one world, and art another. In brief, all things are artificial, for nature is the art of God.'

REHABILITATION OF DEVASTATED AREAS

by

SIR JOHN RUSSELL, O.B.E., F.R.S.

AT the Birmingham Meeting of the Association the Sections of Botany and Agriculture, together with the Sub-Section of Forestry, arranged an all-day discussion on the rehabilitation of derelict areas. Six papers were given and a general account of the symposium appeared in *Nature*, Vol. 166, p. 630. Certain of the individual papers are to appear in other, specialised, journals: references will be found on page 462. The introductory paper on the nature of the problems involved, given by Sir John Russell, is printed below.

SEVERAL important industrial operations are now causing much devastation of agricultural land, among them mining for iron ore and for opencast coal, working for sand and gravel, and the covering of agricultural land by industrial waste materials that cannot be disposed of otherwise. The devastation caused by the first three of these need not be permanent and the conditions under which restoration is possible will be considered.

Sand and gravel workings present on the whole the simplest problems, but they are growing in importance. The pre-war demand for gravel was about 25 million cubic yards per annum; it is now about 30 million. London alone requires about 10 million yards compared with 8·95 million in 1938. Transport is so costly that supplies must, if possible, be obtained locally, and for London and South-East England the Valley of the Thames and its tributaries will probably continue to be the chief source. In the Vale of St. Albans is a belt about 25 miles long and 4 miles wide stretching from Rickmansworth to Ware; the Lea Valley also has substantial deposits and there are others in the Thames Valley west of London. All are likely to be worked in the near future. A Committee of the Ministry of Town and Country Planning in 1948 [1] emphasised the serious situation caused by the dwindling supplies and urged that some 20,000 acres of gravel deposits should be earmarked as gravel-winning areas: even if it meant invading the green belt gravel should take precedence of amenity. There are two groups of gravel pits: the dry and the wet. From the dry pits gravel can be won with only temporary loss of food production provided the surface soil after removal is stacked and then replaced on the levelled floor when the pits are finally given up. It is essential that these conditions should be rigidly enforced. Gravel and sandy soils are well adapted to market gardening, and the value of the produce per acre is so much greater than that of farm produce that special cultivation methods become practicable. Bedfordshire, one of our great market gardening regions, affords some good examples of successful utilisation of old gravel workings for vegetable production. The chief effect has been to lower the level of the land and so long as the water table remains sufficiently below the surface no harm results: indeed, where water is pumped for irrigation purposes there may even be some saving in the cost of pumping. Where Mr. Secrett's method of dissolving fertilisers in the irrigation water is adopted, the process becomes very much like the sand cultures of plant physiologists and agricultural chemists.

More difficulty arises where the rehabilitated workings are going back to agricultural use, because the low returns usual on gravels and sands allow very little margin for special treatment. Cambridge University Farm illustrates a successful case; when extraction of gravel ceased the floor of the pit was levelled, the top soil spread and grass and clover seeds sown; the farm buildings were sufficiently

[1] Report published by H.M. Stationery Office, October 1948.

near to allow the clearings of stackyards and other organic wastes to be carted out and spread so as to increase the humus content of the soil. In course of time a reasonably good pasture has been obtained. In Hertfordshire, also, some of the disused gravel workings have reverted to agricultural use without obvious deterioration.

Unfortunately, during the war the top soil was not always saved and in consequence many pits are left in such a state that they could only with difficulty, if at all, be restored to agricultural use. Some of them are used for dumping of town refuse. Unless the salvage work has been efficiently done, and organic matter adequately removed, these dumps may become infested with rats and become a great nuisance to the neighbourhood, as happened with the London dump at Wheathampstead in Hertfordshire. Where, however, the refuse has been cleaned and the top of the dump levelled, soil removed from building sites can be spread over it and sown down with grass for recreation grounds or, if the layer of soil is thick enough, used for allotments. During the war some of these refuse dumps in Hertfordshire were levelled and cropped with corn, with satisfactory results.

Where the gravel has been worked so deeply that the abandoned pit fills with water, it ceases to have agricultural possibilities, though fish culture might be practicable. In Poland I used to be told before the war that an acre of water could be just as profitable as an acre of land, but we could hardly expect that result here.

The problem of the waste heaps of the Black Country was discussed at the meeting of the British Association at Newcastle in 1916 when an account was given by Mr. P. E. Martineau of the planting with trees by the Midland Afforestation Association from 1903 onwards. The smoke and other conditions proved too much for evergreen conifers, but some of the deciduous trees grew up, notably black and white alder, black Italian poplar, sycamore, various willows, wych elm, birch and ash : the plantations were favourably reported on by Mr. Bastin in 1914. At Bilston after about 35 years Dr. G. H. Bates found that some 4 inches of soil had already formed. A good example of what can be done by trees and grass can be seen in Reedswood Park, Walsall, laid out on land formerly worked for near-surface coal. Much of this type of land is used for building estates, the remainder is probably better suited for trees than for farming, and in any case there are difficulties about tenure and uncertain ownership which make it unsuitable for agricultural enterprises.

The surface workings for iron ore in the Midland counties present much more serious problems. The ore occurs in the Oolite and Lias formations, and it is sufficiently near the surface to be extracted in parts of Northamptonshire, Lincolnshire, Leicestershire, Rutland and north Oxfordshire. It forms bands of varying thickness : those worked are usually about 6 to 12 feet, but may be as much as 32 feet thick. They crop out at or near the surface and dip gradually to the east and south, being overlaid by clays, sands and limestones. Working has been going on for many years, but in the early days when the feeling for conservation of agricultural land was strong, it was always required that the land should be restored to agricultural use after the ore had been taken. So long as the extraction was by hand this presented no particular difficulty : the surface soil was first removed and stacked, then a trench was dug through the 'overburden,' the ore was extracted and the next lot of overburden thrown back into the trench thus left : just as in the old-fashioned garden trenching. Excavations had to stop at a depth of about 10 feet. Finally the surface soil was replaced and sown down to grass ; before long the area was back in its original condition apart from any trees or hedges that had been sacrificed during the operations. Many areas worked in this way some 20 or 30 years ago are now indistinguishable from surrounding unworked areas.

Troubles began when excavating machines took the place of hand labour. One of the first to come into use was the face shovel fixed on to a jib which dragged it up the face of the overburden, scooping up several cubic yards of material ; the jib was then swung round and the material deposited in a heap on the opposite bank. As the machine moved along the cutting it

left behind it this trail of heaps, leaving the surface in a series of long ridges, of varying distances apart, but usually between 9–16 feet, centre to centre, euphemistically called ' hills and dales ' ; actually an appalling eyesore. Unfortunately, at the time there was no sufficiently strong feeling for soil conservation and the operators were not required to restore the land to agricultural use ; they were allowed to compensate the owners at the low prices then prevailing. There was some levelling as a secondary operation but it was purely voluntary. As the machines became larger the height of the ' hills ' or ridges increased and the large 5360 face shovel now normally in use discharges the overburden at a distance of 100 feet in ridges 20 feet high and 40 feet apart. A later type of excavator, the ' drag line,' was better ; as the scoop is carried on steel ropes it was more flexible than the face shovel and allowed the material to be deposited evenly and roughly levelled, making restoration practicable. The largest drag line now commonly in use is a 5W, which can level land and remove and replace topsoil to a depth of 35 feet or more, except where there is a considerable quantity of heavy limestone in the overburden, and which carries a boom of 135 feet in length. As the shallower workings become exhausted, it is necessary to strike more deeply ; larger and more powerful drag lines are being developed. A common depth of working is about 50–70 feet to extract a 7–10 foot bed of ore, but the machines get bigger and bigger ; the latest is the monstrous ' walking drag line,' a machine that can remove 70 feet of overburden and amble along on huge pseudopodial structures, excavating anything up to 19 cubic yards at a scoop with a boom up to 215 feet in length—one is now under construction with a boom of even greater length—but when these machines are worked to a maximum depth they cannot level dumped material as they go along, but leave it in ' hills and dales ' or large undulations which are as bad as those left by the face shovel. The operations and the machines have recently been described by J. R. Menzies-Wilson in his Presidential Address to the Iron and Steel Institute.[1]

[1] 1950, *J. Iron and Steel Institute*, **165**, 129–136.

Unworked ironstone reserves in the Midlands amount to some 116,000 acres of which some 70,000 acres are in Northamptonshire. Much of this is accessible only by underground workings but some 60,000 acres may be suitable for opencast working.

By far the most important beds are in the Northampton sands of the great oolite ; the area already worked was quoted by Mr. Waters (1944) as 18,500 acres : accompanying activities raise this to about 20,000 acres, about half of which is in Northamptonshire, about a quarter in Lincolnshire, and the rest in Leicestershire, Rutland and Oxfordshire in that order. Mr. Menzies-Wilson states that some 7 million tons of ore are extracted yearly which, as the bands of ore are about 7 to 10 feet in thickness, requires the excavation of about 350 or 400 acres a year. Some of the ores are siliceous and some calcareous, and a proper balance has to be maintained to ensure uniform feeding of the blast furnaces with the proper mixture : several quarries have to work simultaneously and in close co-ordination. He expects that another 12,800 acres will be required in the next 20 years, but applications for far larger areas have been made.

So far some 10,000 acres, *i.e.* about half the worked-out land, have been levelled voluntarily by the Companies concerned and returned to agricultural use, but about 3,500 acres have not been levelled. Of this, about 900 acres have been planted with trees, but some 2,500 acres or more are left as ' hill and dale '—a perfectly shocking sight. As the workings deepen and the excavators get bigger the Companies indicate that less of the land will be voluntarily restored and more left as ' hill and dale.'

The Northamptonshire County Council, faced with the devastation of much of their very attractive countryside, has in recent years urged that the Companies should be obliged to restore the land they have destroyed. So strongly was public opinion roused that the Government appointed the Kennett Committee in 1938 to study the question. This body accepted the statements of the engineers that ' hills and dales ' were the inevitable outcome of opencast mining and acquiesced

in the view that they should be afforested. The Northamptonshire County Council in their evidence before the Scott Committee of 1942 pointed out, however, that some 80,000 acres of their County were involved ; if devastated and afforested some 40 villages and their inhabitants would be eliminated. Mr. A. H. S. Waters was asked in 1944 to study the question ; much of his Report is confidential, but a part has been published[1] and he recommended that restoration should be compulsory, adding that engineers would find the way if they were obliged to do so.

Since then, the Town and Country Planning Act of 1947 gives the Minister power to insist on restoration. This has now been exercised in an Order issued in July 1950 requiring that the old derelict areas shall be rehabilitated and that no new ones shall be made.

There are two requisites for restoration. The first and most fundamental is that the land should be left sufficiently level and free from large stones near the surface to allow agricultural implements to work properly. The second requisite is the restoration of the surface soil, which of course necessitates its separate collection and storage. Here, however, there is the possibility of exception in certain circumstances which will be discussed later.

Levelling presents no engineering difficulty where the overburden consists of sands and clays whether estuarine or boulder in origin. Road making and other engineers have designed suitable implements : D.8 caterpillar tractors and modern bulldozers followed by scrapers for grading ; the cost of the work is negligible compared with the value of the ore—much has been done at about £45 per acre but in general the cost is likely to be considerably higher.

Trouble arises, however, where bands of limestone occur in the overburden, as not infrequently happens. Some of this limestone is very hard, and has to be fragmented by blasting so done as not to disturb the wall : it can then be torn out by the scoop in huge lumps which may weigh several tons. These are usually dumped with the soil, and they make levelling more difficult ; even where the surface appears level a rock covered with only a few inches of soil soon begins to project. The problem is to put the rocks well below the surface, either by some selective device that topples them down into the bottom of the gully, or by a double skimming device, whereby not only the top soil but also a deep lower layer is taken off and stored separately, then replaced. This device is adopted by the opencast coal workers and seems satisfactory.

At present—where there is a large percentage of them—these limestone blocks are regarded as insuperable obstacles to the restoration of the land to agriculture, and the apparently Gilbertian situation has arisen that crags and dales in Derbyshire and hillsides near Wells are to be ruthlessly scarred in order to provide limestone, while tracts of land in the Midlands are to lie waste because the limestone cannot be got rid of. The possibility of using it was considered during the war, but was ruled out as impracticable.

The land, though levelled and mineralogically little altered, is fundamentally changed from the pedological point of view. It is simply a churned up mass of mineral fragments, entirely devoid of the structure typical of soils and subsoils in this country, and very deficient in organic matter and in plant nutrients, lacking also the population of micro-organisms and of earthworms that play so important a part in the relations of soils and plants. The mass of material, indeed, is not unlike what the glaciers must have left behind them at the close of the Ice Age. Long continued action of plants, micro-organisms and small animals, of sun, rain and frost was necessary before this mineral mass became a soil. The problem for the agricultural scientist is to effect these changes in our day, not in geological time.

The most important changes are in the top six or nine inches ; the proper crumb structure capable of supplying the plant rootlets with the necessary moisture, air, and nutrients, has to be induced and this is both slow and difficult. Three stages can be distinguished : the fine particles are first built up into granules ; these cluster into crumbs, and the crumbs stick together to form clods. It is essential that the crumbs should be stable, capable of

[1] Cmd. 6906, 1946.

standing up without much change against ordinary rain, sun or wind ; in English conditions a suitable diameter is about 1 to 3 mm. : they are then large enough not to be blown away and small enough to allow good development of seedling rootlets. Further, they must be sufficiently mellow, *i.e.* free from much stickiness when moist so as to retain their individuality during cultivation. The mechanism of the formation of granules and crumbs has been much studied but it is still far from clear ; investigations are proceeding at Oxford by E. W. Russell and at other places. Still less is known about the cause of mellowness : it is easily recognised, but its attainment is so far an art rather than a science. The aggregation is effected by clay, *i.e.* particles less than 0·002 mm. in diameter, and by humus : the relative effectiveness of these two agents has been studied by Demolen and Hénin. Not all clays, however, are equally effective : those with high base exchange capacity give more stable aggregates than those of low exchange capacity (McHenry and Paterson) ; calcium clays are particularly good. Similarly not all soil organic matter is equally effective : Swaby has shown that the most effective humus constituent is α Humic acid and its calcium salt, while fulvic acid is the least effective. In natural conditions the clay and humus apparently act together : the clay particles are shown by the electron microscope to be coated with humus (Kroth and J. B. Page). How this comes about is not certain : Kroth and Page consider that the humus is absorbed, while Chapek and Sakum consider it to be mechanically entangled. Another view (Jung and Meyer) is that the coating is effected partly by polar bonds, partly by molecular and partly by Van der Waal's forces.

Crumb formation obviously requires much mingling of the surface material. To some extent this can be effected by the ordinary cultivation processes, though these by themselves cannot do very much. Growing plants with a large and fibrous root system, such as some of the grasses, lucerne and the clovers, disseminate organic matter through the soil, forming soil aggregates, which are more stable than those on arable land. But the most effective mingling and aggregating agents are the earthworms which slowly but persistently pass quantities of material through their bodies, thoroughly mixing it, and in the process building up crumbs which are more stable than those formed in any other way. The most stable crumbs are those formed on grassland, especially those formed by earthworms : R. J. Swaby of Rothamsted shows that these contain much macerated grass and large numbers of bacteria, but little fungus mycelium ; he attributes the aggregation to gums produced by bacterial decomposition of the grass. But although fungi do not seem to be active in the bodies of earthworms they play an important part in building up aggregates in the soil.

The establishment of stable soil crumbs, however, is not enough ; it is necessary also to have a stable system of soil pores small enough to retain water by capillary action, but large enough to allow the rootlets to extract it, and these must link up with a continuous system of channels of diameter larger than 60 μ through which water can move freely downwards, thus allowing adequate air supply to the roots even in wet weather.

It is not necessary that soil crumbs should be formed in the depths below 6 or 9 inches, but a complete system of channels allowing of percolation of water down to the drainage level is essential.

Considerable time may elapse before a stable system of such channels is established. In the new conditions the material is much looser than in the original soil and the packing is much more open. Eight feet of iron ore may have been removed, but the surface may be lowered only 3 or 4 feet. In consequence of this open packing there is a tendency for the finer particles of the surface layers to be washed down below ; this, if unchecked, would not only be a serious source of loss to the surface but would greatly interfere with the air supplies of the roots by blocking up the passages along which excess water would drain away and air could enter.

Settlement and consolidation may go on for years and stable water relationship cannot be established until they are well on the way to completion. The lowering of the surface level may bring in water from the surrounding ground, rendering

drainage necessary, yet drains cannot be laid until settlement has proceeded sufficiently. This often causes particular trouble in the restoration of the opencast coal workings in Yorkshire. In a normal soil an expert can usually, without much difficulty, devise an effective drainage scheme and forecast the results with reasonable accuracy : in the new conditions he cannot. The drastic change in the whole profile of the soil has completely altered its water relationships : both its capacity for holding water in its pores against gravity, and its power of transmitting to the subsoil some or all of the water in excess of the quantity thus retained.

Drainage may be particularly hampered if the restoration has been done during wet weather ; the heavy tackle puddles the clay material forming an impervious layer which does not subsequently break up when more material is deposited. In consequence patches of the restored soil are liable to become waterlogged. This commonly happened in the West Riding in the early days of restoration and hence operations there are now suspended between October and March.

Restoration of these worked sites to agricultural use thus necessitates the attainment of three sets of conditions : (1) the building up of a proper and stable crumb structure in the surface soil ; (2) the establishment of a proper system of stable pore spaces to allow the downward percolation of excess of water and the free access of air to the roots ; (3) a stable system of channels in the subsoil to allow the excess of water to pass into the drainage system.

The building up of the crumb structure requires, as we have seen, the basic materials ; clay of a rather special kind, and humus ; and as agents, earthworms, soil bacteria and soil fungi. If sufficient clay material is present it can be converted into the proper chemical type (a calcium clay) by application of lime, but where it is not present in adequate amount, its place can be taken by organic matter which will be needed in any case. As already stated, this is best supplied by the growth of crops, the roots of which can permeate the soil and on dying, decompose to form humus, meanwhile furnishing food for the population of soil bacteria and fungi, which rapidly establishes itself, and for earthworms, which come in more slowly.

As a general rule crumb formation, and at least some degree of mellowness, can be most rapidly induced by the roots of growing grasses and to a less extent by clovers. Fortunately also clovers—especially red clover and S100 white—and certain other leguminous plants, lucerne and, to a less degree, Sainfoin are among the most tolerant of all plants of the conditions obtaining in raw unmellowed subsoil—as can be seen in any railway embankment. The combination of grass and clover is more effective for building up soil structure than clover alone. In all probability the different grasses differ considerably in effectiveness, but it is not known which of the grasses is the best to use in England. In Canada Crested Wheat Grass (*Agropyron cristata*) is much more effective than Slender Wheat Grass (*A. pauciflorum*). Where this procedure is adopted the first agricultural operation is to sow a mixture of clover and grass and by suitable management to encourage as much growth as possible so as to ensure the maximum amount of root action, establishing a good soil structure and at the same time supplying one of the chief deficiencies : nitrogenous organic matter, one of the fundamental bases of soil fertility.

If the clover and grass mixture can survive permanently and respond to the standard methods of improvement the agricultural problem is well on the way to solution. A serious difficulty is, however, that the grasses may die out after the first year or so, even though at first they look quite well. The reason is that surface conditions permitting the germination and growth of seedlings are easier to obtain, especially in dry spring weather moderated by occasional showers, than to maintain over several seasons. The grass and clover mixture, so effective in other respects, is usually grazed periodically to ensure its proper maintenance, and the trampling of the animals is liable to destroy the system of pores and the crumb structure before they have attained permanent stability. For this reason in some regions, particularly Yorkshire and Lancashire, a

course of arable cropping is preferred, in which the crumb structure is attained by cultivation. This I shall discuss later.

Whichever reclamation method is adopted: whether a mixture of grass and leguminous crops, or a course of arable cropping, the management of the material during the process of soil formation is far removed from ordinary farming: the cropping and the yields may remain subnormal for a number of years, necessitating financial subventions of unpredictable but sometimes considerable amounts. These attempts to accelerate soil formation present some fascinating problems in soil science and it is much to be hoped that some competent investigator will take them in hand.

These problems of restoration are enormously simplified if the top soil has been separately removed and stored and then replaced on the levelled surface of the excavated material. For this reason agricultural experts attach the greatest importance to this replacement. Many problems still remain. During its storage, and as the result of the movement to the dump and back again, the surface soil suffers some deterioration of structure, and there is also said to be some adverse chemical change, though of this I have been unable to find any evidence. But any such deterioration can soon be righted by the application of fertilisers and a suitable scheme of cropping and cultivation. The subsoil may continue for several years to give trouble through subsidence. There still remains a further difficulty: the high power of fixation of P_2O_5 by some of the minerals, thus greatly reducing the efficiency of phosphatic fertilisers, of which the plants stand in great need. No easy way round this trouble is known: it tends to diminish under good management; it can be evaded to some extent where cereal crops are grown by placing the fertiliser in a narrow band alongside the seed instead of broadcasting it in the usual way.

The restoration to agricultural use is thus beset with many difficulties, but they can all be overcome by taking sufficient trouble and in my view they should be overcome.

Afforestation has been recommended as a way of avoiding all these difficulties. The Scott Commission considered that it should be adopted only as a last resort, and with this I entirely agree. Its merit is that it saves the trouble and expense of levelling and replacing the top soil: indeed it is claimed that the trees make better growth on the hill and dale than they would on the level and this is borne out by experience in the United States. A small area to furnish some of the timber needed may be justified and may even have an amenity value. But in this country land capable of effective food production should not in my view be afforested.

The iron ore problems will always be with us, for this particular ore is the basis of Corby's industry, and Corby is planned to grow from its present population of 13,000 to a town of 40,000 inhabitants most of whom will depend on the iron-works for their living. When the surface deposits are exhausted there will still remain the much larger reserves of ore to be won by deep mining which will involve agriculturists in the difficult problems of subsidence.

The position is different in regard to opencast coal mining. This began on any important scale only in December 1941: up to March 1950, 65·9 million tons of coal had been got: the present rate of extraction is about 13 million tons a year. The Government has decreed that coal mining must pay its way, and under these conditions only about 66 million tons are said to remain for extraction. We may expect, therefore, this particular problem to disappear in a few years' time.

By the time that opencast coal mining began the devastation caused by the iron workings had become so serious and aroused so much public anxiety that the contractors were from the outset required to restore the land to agricultural use after removing the coal. They have therefore done this. They are further required to put large blocks of stone at least three feet below the surface so as to avoid the possibility of emergence at or sufficiently near the surface to interfere with cultivation. This also has been done either by selective dumping or by a second skimming to provide enough material for a 2 or 3 foot cover before the surface soil

is replaced. The operations destroy trees, hedges, ruin the landscape and, an even greater blot, while they last they inflict great hardship on farmers by depriving them of part or all of their livelihood with very inadequate compensation. In the end the land is restored to agriculture, but recovery is still slow. As already stated an impervious layer leading to water-logging may be formed by poaching of the land if the restoration is done in bad weather : contractors cannot always be prevented from doing this. Drainage is one of the main problems : it cannot properly be undertaken till subsidence is well advanced. In the West Riding the land is held for five years before being finally derequisitioned by the Ministry of Fuel and Power, the body responsible for ensuring restoration, in order to rectify drainage defects. The legal obligation to restore, however, applies only to agricultural land and not to land under woods or coppices. When these are cleared for mining the land could frequently be used for agriculture if restored, and it is unfortunate when such opportunities are missed.

The soil problems are so similar to those of the iron ore workings that they need not be further discussed. Formerly the procedure in Lancashire and Yorkshire was as in Northamptonshire, to put into grass and use for grazing. But frequently the grazings deteriorated rapidly. Arable cropping is therefore used for the first few years including wheat, summer fallow, and one-year leys, during which time the lack of plant nutrients can be remedied : this has been successfully used by J. Gibbons, the Agricultural Officer of the West Riding. By the time grass and clover are finally established subsidence has proceeded so far that drains can be laid and the land handed over to the farmer.

The question naturally arises : if the opencast coal workers could level the land in spite of bands of rock and put back the surface soil, why could not the opencast iron ore workers do the same? The answer given was that the coal is worth much more per ton than the iron ore and the contractors have therefore considerably more money at their disposal. Against this was the view expressed by Mr. Waters that if the ironstone contractors were required by law to restore the land ' this would in all probability lead to the development of further modifications in the excavating machinery and in operational techniques, and progress in restoration methods would soon be considerable.' After years of waiting this is to be done.

The new Order requires—

(i) complete restoration, with replacement of topsoil, in all cases except—
  (a) where the length of face being worked is so great that the cost of replacement of topsoil would be very high ;
  (b) where the content of the overburden makes impracticable the restoration of the land to agricultural use ;
  (c) where, in the interests of agriculture, replanting or establishment of woodland is advisable, for example, to provide windbreaks and maintain supplies of estate timber.

(ii) Where complete restoration, for the above reasons, is not practicable, levelling without replacement of topsoil, followed by careful cultivation and special use of fertilisers ;

(iii) where restoration to agriculture is impracticable, afforestation, either on levelled land or on land left as ' hill and dale.'

It is further stated that, in future, 75 per cent. of the cost of the restoration shall be borne by the producers and royalty owners and 25 per cent. by the Exchequer. In regard to the land at present derelict it is hoped in some cases to make voluntary arrangements with the owners ; in other cases local authorities will be authorised to acquire the land and restore it with the aid of Exchequer grants.

These measures properly carried out should suffice to prevent permanent losses of agricultural land from these particular causes and we can only congratulate the Minister of Town and Country Planning for having initiated them.

ENERGY IN THE SERVICE OF MAN

In connection with the Birmingham Meeting of the Association, the Local Committee arranged a series of five public lectures on the theme of ' Energy in the Service of Man.' These lectures were intended to be complementary to an exhibition on the same topic sponsored by the National Coal Board, Gas Council, British Electricity Authority and the Common Good Trust. The exhibition was open to the public before and after the Meeting and to members of the British Association during the Meeting. With one exception, the public lectures were given before the Meeting opened. This meant that visiting members had no opportunity of hearing them and for this reason it has been thought desirable to publish the texts of the five lectures and these appear in the pages that follow.

CIVILISATION AND THE USE OF ENERGY

by

Sir ALFRED EGERTON, F.R.S.

No one can hold now that man is not conscious of his actions in relation to the use of energy. Part of the world's troubles in the near past has been that the purpose of man's main activities has been insufficiently appreciated. The setting of the stage has not been clearly seen. It is no longer so. We have no excuse for ignorance of the impact of the use of energy on civilisation. As Sir Harold Hartley said at the end of his Presidential Address ' On man's wise use of energy depends the future of this troubled world.'

This evening I cannot do much more than emphasise some of the matters which Sir Harold has brought forward, for the title of my lecture ' civilisation and the use of energy ' is really synonymous with ' energy in the service of man.' Much of what I shall say will be commonplace to many of you and some of it will lack the expert's knowledge, but one cannot be economist and every other kind of ' ist ' as one should be to deal with such a vast subject as civilisation. The emphasis of my lecture will be mainly on civilisation.

The President drew attention to that great addition to man's intellectual armoury which was acquired 100 years ago—the formulation of the laws of thermodynamics. Up to then heat and the power provided by it had been a mystery. It is difficult now to realise that mystery for the laws governing the transformation of energy are intrinsic in the tremendous structure of scientific knowledge which has since been built.

It is not quite 50 years ago that the theoretical conception of the convertibility of matter and energy was defined by Einstein. The work of Rutherford has made reality of this conception. Man, conscious of power over Nature's vast resources of energy, must grasp his flaming sword and cast fear of his destiny aside and be faithful to his highest aims.

Neither the word ' energy ' nor ' civilisation ' is easy to pin down or define. They both have deep-down roots attaching to the meaning of things. Energy is associated with action or the possibility of action. In Clerk-Maxwell's phrase, to which Sir Harold Hartley drew attention, it is ' the go of things,' but in the limited sense in which we shall need to use the word it is measured in joules, and power, in scientific terminology, is just so many joules per second.

The word civil is applied to a citizen community and therefore to man's gregarious state—his integrated interdependence. Man is brought out of a state of unreasonable barbarism into a condition of more reasonable and conscious

development by the aid of intellect, man's special attribute. It is not a stage in man's evolution but the path or 'go' of his natural evolution.

The early stages of man's emergence and development are still wrapped in much mystery. From one million years to about 30,000 years ago there are, after all, only a few patches of solid fact. To Upper Palaeolithic times, there was a period 200 times as long as from the dawn of history to the present day. From Upper Palaeolithic times to the ascendancy of Neolithic tribes a period of about four times as long, and after that, in the Neolithic period, it seems some of the main steps to civilisation were taken.

There is one feature of the vast period of man's prehistory that is of special concern to us in reviewing things. There is no evidence that man has been without possession of fire. Sumner and Keller, who studied this aspect of man's development and so far as I am aware their opinion still stands, state that 'over the whole earth there is no fireless tribe of men and man is scarcely man until he is in possession of fire.'

It may well be that fire, once man had put it to his use, was the chief instrument of his supremacy over the animals. In glacial times, when man took to the caves so did the lions and bears, but fire protected man. While man sought food, the fires had to be tended, the family had to be kept together, and so began man's interdependence. 'Keeping the home fire burning' is perhaps man's most priceless motto. The legend that Prometheus brought fire to the earth by lighting a torch at the sun's chariot is a picturesque statement of the many ways by which Nature starts a fire—by volcano, by meteors, by lightning, by friction or by sparks from falling stones. The fear of fire was mastered. I want to stress this effect on man's interdependence which is an essential to civilisation. The protection of the young is potent towards collaboration but that factor is common in many living species. To keep the home fire burning meant collaboration of intelligence to meet emergency. It meant reasoning and forethought on man's part beyond Nature's urge to propagate the species.

In order to give effect to collaboration, gesture, mimicry and eventually speech must have developed. Without collaboration and imitation, the making of tools and weapons would not have come about. It had to be realised, too, some time or other that the force of two applied in the same direction had more effect than one in that same direction. That was perhaps the first step in man's appreciation of the laws governing energy—the laws of dynamics. However, man's mastery of fire was a very important factor in bringing about his ascendancy, eventually leading to civilisation.

The getting of food and water sufficient for life and its continuance was, as for every creature, of course the main urge; and gradually man devised ways of making this easier. Soon he tumbled to the idea of keeping herds and protecting them from wild animals by fire, and then collecting seeds and sowing and harvesting; cooking by fire which led to the making of pots from clay; and eventually the smelting of copper and bronze by fire was contrived.

Man needed to enlarge his stores of food. Forests had to be cleared, and hardened bronze and iron helped in the battle with the forest. But the metals were perhaps more in demand for tribal strife in struggle for the riches which other tribes had won from the earth.

Man found that just as two men's labour could be more effective than one alone so he could make use of the power of his animals, his herds, his oxen and his horses, and gradually they were domesticated. So civilisation came; man's genius, fire, interdependence, speech, the directed use of energy, and the written word brought it about.

Reverting to the dawn of history, recent excavations have done much to illuminate the earliest times, and there follow Babylon and Egypt, Assyria and Persia, China and India, Crete and Phoenicea, Greece and Rome—5,000 years. Rome, Christianity and Islam, the Crusades and the Mongol conquests—another 1,500 years pass by. Then comes the flowering of the Renaissance in Europe, about 500 years ago, and with it the enlargement of man's realm, not only by exploration and colonisation but by the invention of printing.

The New World is discovered, the dying echoes of its past civilisation fade away. The fruit of the Renaissance in Europe, experimental science, ripens. It heralds a new age, commencing only about 300 years ago. New sources of energy, got by new ways of harnessing the energy of combustion of coal, become available. That was only about 150 years ago, producing the Industrial Revolution and a great expansion of population and power. In the last 100 years civilisation—so called—has gone apace. Man acquired all sorts of new powers, new ways of transforming energy (electricity), new fuels (oil and gas), new means of transport (flight), new means of communication (radio), new conquests of disease.

The pace has been indeed too great. The wit of man, not knowing perhaps fully what he was about, failed to contrive adjustments necessary to maintain stability in world affairs—neither political nor economic. Strife ensued—wars which have not only resulted in still further quickening the pace at which man is making use of natural resources, but in awakening in him apprehension and a greater consciousness of his activities. Sweeping through history in this way is perhaps inexcusable, but I wanted to get the time scale for our considerations.

Food and fuel are the two most potent factors affecting civilisation. The basic fact is that man requires a certain amount of energy to maintain life—8,000 kilojoules per day or 1,900 calories. Extra energy at his disposal provides scope for his activities, widening his power of obtaining the food that gives him the energy and allowing expansion of the race.

Other material factors affect civilisation, such as supplies of water and constituents of food other than its energy-bearing content. They are of importance, providing the constituents of food protective to health (nitrogen, phosphorus, etc.). For plant life, many different soil constituents are essential. Nevertheless these are not the major factors because their acquisition is rendered possible provided energy is available.

The events of history, particularly the earlier periods, are not just a matter of energy, of population spread controlled by the energy of food and the fuel available. They have been determined by numerous factors. The desire to grab what other tribes had acquired—avarice, covetousness and envy have been, and are to this day, very potent factors. Personalities, leaders who represented and expressed the emotional urge of their followers have of course influenced events. Men have from time to time seen the error of their ways and the consequences of selfish action off the path of interdependence and collaboration. Geographical, climatic and racial differences have also greatly affected the course of civilisation.

In early times, with the methods of primitive agriculture in vogue, it required perhaps 500 square miles of territory to keep a great city of about 200,000 inhabitants supplied. That could not have been outside the powers of transport by oxcart and boat. The methods of cultivation were not perhaps greatly different from those of some parts of India at the present time, where average yields of wheat range from 600 to 1,100 kilograms per hectare. In Britain in the thirteenth century Walter of Henley thought 10 bushels of grain per acre a fair return and that is about the same yield. The population then might have been 1½ million. The area of cultivated land was probably only about 1–2 million acres, instead of the 31 million under cultivation in the United Kingdom now.

More often than not it seems that the cause of decline was not so much the sheer lack of ability to find the food for a growing population as the urge of other communities to take their wealth. There was generally land enough to support the population, for natural forces, droughts, floods and pestilence, took their toll and kept population in check, even in days of comparative peace. There was often indeed a surplus of products and man ventured far and wide, sailing the seas in ships, to gather gold and riches from other lands. Such is the story of the earlier years and this state of affairs was much the same until the sixteenth century.

The limitation to man's sway in early times was not so much the limitation of area of land but a matter of temperature. Man without means of combating extremes of temperature was forced to live in regions of warm and healthy climate.

There have been many studies of the influence of climate on civilisation. It is clear that the early centres of civilisation were around what is called the 70° F. isotherm, regions averaging that temperature during the course of the year. Man lightly attired is not much bothered by a climate which does not go lower than 60° F. or higher than 77° F. and with relative humidities between 44 and 77 per cent. There are few places which provide such conditions and the climates where early civilisation arose were often warmer rather than colder than this ideal.

TABLE I.[1]

	I °F.	II °F.	III %	IV °F.	V %
Portugal . .	60	50	81	71	63
Mexico . .	61	55	58	66	70
Syria . .	62	48	80	76	66
Greece . .	63	46	74	81	52
Palestine . .	64	48	76	77	66
Morocco . .	65	53	78	79	66
China (S. of 30°) .	66	47	72	83	82
Egypt . .	70	55	65	82	57
Iraq . .	71	48	80	85	43
Salvador . .	74	71	84	76	72

I Mean Annual Temperature
II ,, Temperature during coldest month
III ,, Humidities ,, ,, ,,
IV ,, Temperature ,, warmest ,,
V ,, Humidities ,, ,, ,,

The line wanders in a wiggly belt round the earth in the lower part of the north temperate zone through the centres of early civilisation—the South Mediterranean, Mesopotamia, Asia Minor, Egypt, Assyria, Phoenicea, valley of the Indus, South-East China and Central America. Several of the regions in Table I are outside the range of temperatures 60° to 77°. Palestine comes near to it but it is cold in the winter. Egypt comes near but it is a little hot at certain times of the year.

Although the causes of rise and fall of early centres of civilisation are many, it has only to be realised that no really great centres of civilisation are to be found in cold temperate regions in order to conclude that climate was the dominant factor affecting the extension of civilisation. It was not until control of temperature conditions became possible that civilisation could be established permanently in more northerly cooler regions.

The first great centre of civilisation which was not quite within the 70° regions was Greece. But the Greeks are said to have devised the hypocaust system of heating by burning fuel and warming the walls of their houses by the heat of products of combustion as early as 750 B.C. It may be in the kindly climate of Hellas it was not necessary to make use of the system very often, but the Greeks hereby had means to control their climate and they were no longer at its mercy. Nevertheless population never became very large in Greece, as it did in fertile Egypt. Athens could not boast of a population of more than 165,000 free citizens and 120,000 slaves. Rome with its population of four million citizens in 122 B.C., was the first large centre of civilisation with a large part of its population outside the regions of the 70° isotherm. Rome had developed the hypocaust system and was no longer restricted by temperature limitations.

Markham[2] has developed the thesis that expansion of civilisation outside the 70° isotherm is only possible by control of climate through systems supplying heat, and holds that when Rome fell it was inevitable that the centre of civilisation should revert to more southern regions. So it was that civilisation spread from Rome to Constantinople and then went south and through the rise of Islam spread from Arabia along North Africa and eventually back to Europe *via* Spain. Not until after A.D. 1350, when the chimney fire makes its appearance in Italy, does climate control become again a potent factor and gradually the vigorous northern countries gain ascendance.

The control of climate by use of fire in cold regions has now rendered practically the whole world habitable and changed the restriction of expansion which had existed from the earliest times to the time of the Renaissance except during the Roman period.

In the early historical times, and even to-day in large parts of the world, the muscular power of man and his animal

[1] From Markham, *Climate and the Energy of Nations*. Oxford (1942).

[2] *Climate and the Energy of Nations.*

helps provided the means to do work. Thousands of slaves supplied the energy for great undertakings like the Pyramids, or the wonderful aqueducts built by the Romans, which kept cities supplied with water in those early times. The energy, of course, is derived from food.

A hundred h.p. would probably have been about the maximum power which could conveniently be applied by slave or animal power to any specific job. A man can do on the average about 700 foot tons of work per day of eight hours and would need about 2,700 calories (or 11,000 kilojoules) in his food for maintenance and work. A horse can exert 10 or 12 times the power of man, but his work cannot be counted over so many hours and it is usual to reckon four or five men's work over the year equivalent to that of one horse. The work of an ass is counted much the same as that of a man.

TABLE II.[1]

Horse	800	hrs./yr.	at	1	hp.
Ox	"	"	"	$\frac{11}{12}$	"
Mule	"	"	"	$\frac{3}{4}$	"
Ass	"	"	"	$\frac{1}{4}$	"
Man	2,400	"	"	$\frac{1}{12}$	"

600	kWhrs./yr.	
550	"	"
450	"	"
150	"	"
150	"	"

The bucket, lever and man still act as pump and engine for irrigation in many countries even to-day, but various contrivances enabled mules and oxen to provide the power and take the place of man. Water mills for grinding corn were used in Roman times and the windmill no doubt had its origin in antiquity, but the earliest records of the windmill in Europe seem to be in the twelfth century. Many villages would have their flour mills and in 1870 there were about 10,000 in England. Then came the roller mill and the old independent flour mill went out of use.

A measure of the energy of all the wind and water mills in use at various times for corn grinding, weaving and pumping is not easily obtained, but the total energy in relation to that supplied by animate power was a small proportion, so that food and fodder was the main source of energy up to the eighteenth century. This state of affairs was certainly the same as it had been from the earliest historical times.

In Asia and Africa to-day the ratio of animate to total energy is only about 50 per cent.—that is to say there is as much animal and man-power used in Asia as there is power from fuels and other sources. By contrast in countries like America the ratio is as high as 97 per cent. in favour of the use of ' stored energy,' (energy derived from the sun in past ages and stored in the form of coal, oil, natural gas etc.).

We can now summarise the main factors affecting civilisation up to the Renaissance—indeed till later still—food, aggression, disease. In the early days the learned people, the high priests, were able to do something by mystical methods to help the first factor, but there was a limit to what could be so achieved. It was somewhat the same in relation to what they could do about disease until the beginning of the scientific era. So their influence was mainly on the aggression factor. Some urged the cause of victory, others inveighed against tyranny, but great teachers and great events had

TABLE III.[1]

	A. Animate Million Units	B. Inanimate Million Units	Ratio *inanimate* Total	Per cent. of world total	Units per capita
N. America	24,597	947,552	97·5	36·9	6,860
Middle and S. America	28,406	51,474	64·3	3·0	610
Europe	55,129	877,889	94·1	35·4	2,356
U.S.S.R.	27,658	207,713	88·2	9·0	1,380
Africa	19,691	30,610	60·9	1·9	344
Asia	168,150	171,299	50·5	12·9	305
Oceania and Australia	2,236	22,357	90·9	0·9	2,488
World	325,867	2,308,894	87·6	—	1,250

[1] From *Energy Resources of the World.* U.S. Govt. Printing Office (1949).

demonstrated the ultimate inefficacy of aggression.

Beyond all this materialism which we have been discussing there was something deeper and more durable ever stirring within the spirit of man. How otherwise would he have achieved such glories as Chartres, the sculpture of Greece and the paintings of mediaeval times—outward signs of the inner striving of man towards a higher destiny.

With the Renaissance, however, a change in the material situation began. Two new motivating factors began to alter the scene and produce a new era in civilisation. These two factors were the development of science and the utilisation of stored sources of energy. The new era was established not solely because sources of stored energy came to be used, nor solely because there was a new spirit of enquiry and a harvest of discovery. A long time before the era was launched coal had been used not only for producing warmth but for industrial processes. It was quite a long period, too, from the advent of experimental science to the time when its fruits had economic effect. The great changes came about when both these factors began to affect each other.

Coal was known to the Greeks and to the Chinese in the Han dynasty. The town of Newcastle was granted a Charter to dig coal in 1239 and coal was dug also in Europe in those times. Houses were then without chimneys and as a means of warming the smoke made coal an unpleasant fuel. Its chief use was for lime burning and it was also used by smiths and glass makers. Nevertheless, as chimneys came into use a considerable trade with London had developed in ' sea coal and pitt coal,' so much so, that by the seventeenth century, smoke became a nuisance.

In the sixteenth century wood, the main fuel, was becoming scarcer, for considerable quantities had to be cut ; some to burn to charcoal for the production of iron and some for timber for building ships and houses. An urge for a substitute for charcoal arose. Coke from the combustion of coal eventually became that substitute, but it was first used in 1640 for drying malt for the brewing industry and it was not until 1709 that Abraham Darby introduced coke for the production of iron.

The coal production in Britain in 1660 was only two million tons and in 1770 was only about six million tons and if the increase of coal was a measure of industrial activities it was not particularly remarkable in extent. The coal per head had increased from about 0·4 to about 0·9 tons. In 1800 it was one ton per head and was mainly used for warmth.

The invention of the steam engine was, of course, the chief influence bringing or opening out the new era, for man had new means to utilise the energy at his disposal. No doubt this new source of power brought about in the nineteenth century great changes, but as has been indicated the full cause lies deeper. It is to be found in the change of outlook which had permeated western civilisation. No longer was Europe enmeshed in authority, and the fetters of the past, but man was adventuring into the unknown and facing the future with a new tool, experimental science.

The invention of printing had a great influence in helping to unloose the hold that past authority possessed. The exchange between one mind and another was less confined, and the record of man's progress became far easier. The clouds gradually rolled away. Man increased his interdependence and, at the same time, his individuality.

The experiments of Gilbert, of Harvey, of Galileo became known and discussed. Bacon and Comenius set out new conceptions. Scientific academies were founded in Florence, in Paris and in London. There was a desire to probe Nature, and a delight in Nature's response. The blossom came with Boyle, Hooke, Leeuwenhoek, Huygens and with Newton, there was blossom to the full.

Some think that it is exaggerated to look on man's advance since the Renaissance as due to his utilisation of the experimental method. It is true that a great liberation of spirit was brought about by the humanists. But the heritage of Greece, the recovery of past riches, and their influence on current literature and art would have been in danger of producing sterility in the garb of authority, had it not been for the adventurous spirit

which at the same time arose and which drove the west to explore the world and to explore Nature. It is doubtful whether Watt's invention would have come to fruit, unless western civilisation had undergone those great changes. In the new atmosphere, invention thrived.

The steam engine was indeed a new way in which man could provide himself with an almost unlimited amount of mechanical energy wherever he needed it. The difficulty of transporting food and goods was a major factor preventing rapid growth of centres of population in previous times. The application of steam power in place of wind power for the propulsion of ships also assisted the conveyance of food to large centres, enhanced the importance of ports and stimulated commerce. These developments necessarily had a wide effect on metallurgical and engineering industries. Railways and ports demanded schemes of civil engineering on a scale greater than ever undertaken by man. These new means of taking advantage of the stores of energy in coal greatly increased the amount mined. Changes came so rapidly that maladjustments occurred and many social difficulties arose. Nevertheless once started there was no halting the extension of man's activity ; in Europe and later in America there came the same changes in civilisation. The influence of western civilisation rapidly extended to the rest of the world. As population increased in northern countries so more and more coal was needed. The burning of so much coal inefficiently had caused smoke and gloom in many an industrial city and banished nature from the ken of its inhabitants. There was little enchantment in the enchanting story of man's acquisition of energy.

The interval between the utilisation of a new principle, process or product by civilised man, and its discovery varies according to a multitude of factors. Sometimes the state of technology is such that a new device or discovery can be quickly applied ; or the time is not ripe and many difficulties have to be surmounted before the way is clear. It took 50 years from Boulton and Watt's first engine to Stephenson's locomotive. It took about 50 years from the time of Faraday's discovery to the public supply of light and power. It took 50 years from Fulton's *Clermont* on the Hudson River to the launching of Brunel's transatlantic giant the *Great Eastern.* It may take 50 years from the time of Rutherford's first disruption of the atom to the first large generating station run by an atomic pile. The big steps take time, but the little steps go quicker and quicker. Big trees take time to grow and bear fruit, the smaller plants in the garden grow quicker the richer the soil becomes.

Great Britain was the first starter in the race to utilise stored fuels. In 1800 only one ton per head was used. A hundred years later over six tons per head. The United States did not catch up till 1900. They now use over eight tons per head, including the equivalent in oil and gas.

One of the first major effects of the increase of energy available to man was to increase industrial activity and urbanisation in those countries using stored fuels. This in turn had its effect on world trade and on the countries supplying food and raw materials. Although energy was not at first applied to any great extent to supplement muscular power of men, horses and oxen in these countries overseas, it came to be used to help in providing schemes of irrigation and transport to increase productivity and to assist distribution. It made it easier to bring the products of cultivation to centres for treatment and preparation in mills and factories operated by power derived from fuel. Later, machinery was introduced into the fields and plantations, but still deriving energy from animal power. It is only recently that animal and human muscular power is being greatly supplemented on the farm by energy derived from fuel for actual field operations.

The effect of energy on population changes in the civilised world cannot be discussed in a few sentences. The rate of increase of populations is dependent on many factors, economic, social and political. The chief factor which has operated in producing increase in recent times is the decrease in the mortality rates. When industrialisation has become established, fertility rates, which rise at first, seem then to diminish, and this fall to some extent neutralises the influence of the decrease in

mortality rates and slows down the rate of population increase. There are many other factors which have their influence; for instance, migration from one country to another is particularly important. In the past population had been kept in check by the mortality rate, due mainly to famine and disease. The population of England and Wales only increased from about one million to ten millions in the eight centuries before 1800, whereas within a century from then it increased nearly fourfold. In America it increased nearly sixfold in the same period. The world population increased in the same period about 1·8 times. The present world population is considered to be 2,300 millions within an error of about 10 per cent., and it is increasing at the rate of about 1 per cent. per year. The percentage compound interest rate of growth is increasing also and this is what worries some food experts as three-quarters of the world's population is already below satisfactory nutrition standards.

Population, particularly in certain parts of the world, increased rapidly around A.D. 1800. The connection with the energy story is obvious.

Next we ought to look to see what the present position is regarding the use of energy. So far we have only reviewed what has happened during the past, and seen that when the effects of experimental method and the use of stored energy converged 150 years ago, civilisation acquired a new aspect, and a new era became established.

First let me direct attention to a diagram which is intended to sum up human activities in such a way that they can be grasped easily.

In the centre of the diagram there is a circle representing the sun, the main

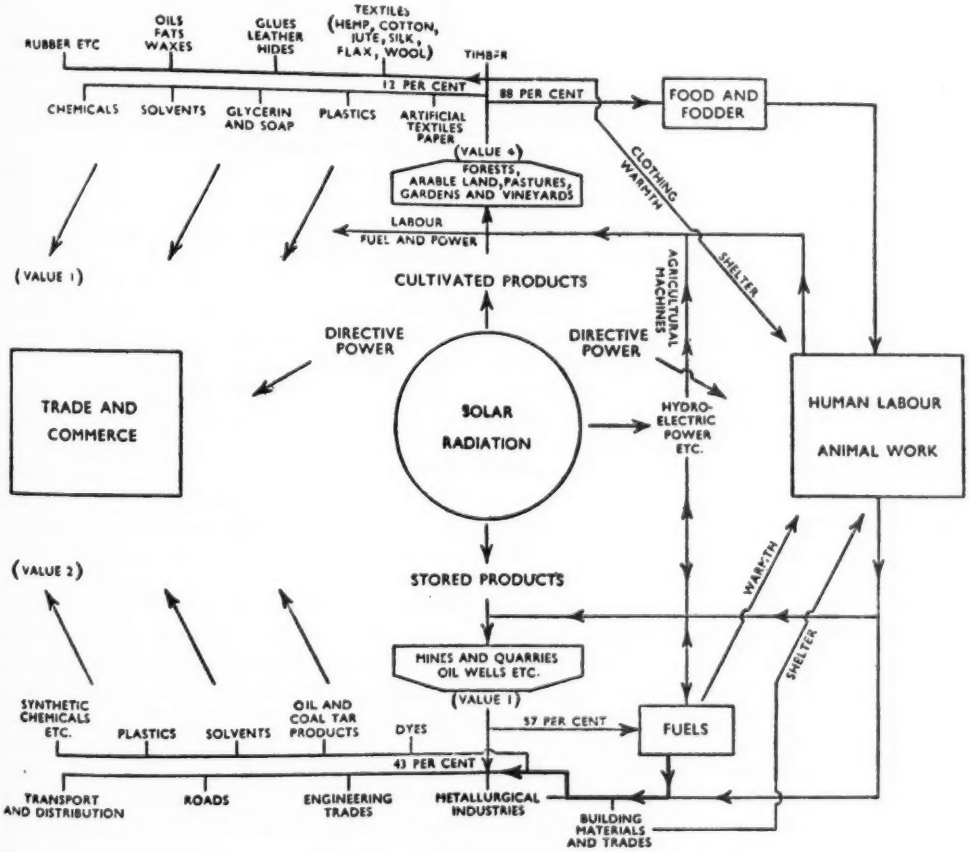

Diagram of Human Activities.

source of the energy which man uses. From this centre a line is drawn upwards to a position representing the conversion of the sun's energy into all the cultivated products, including the products of natural plant growth and the animals, too, which obtain their food from the plants. In fact, not only man's food (grain, fruit, etc.) and the fodder for his animals, but the products timber and wood ; cotton, flax, hemp and rubber ; cattle and sheep (and pigs and poultry and fish) ; wools and hides, silk, oils, fats and waxes—the whole gamut of activities which emerge from forestry and husbandry and the cultivation of the soil.

Then there is a line drawn downwards to a position representing the quest for the products stored from the sun's energy in past ages—the coal mines, the oil wells and included in this (though not the result of the solar radiation) are the quarries, the metalliferous mines and the gravel and clay pits and so on.

To the left of the upper part of the diagram there are two lines, the top representing the products of cultivation, husbandry and forestry which form the basis of subsidiary industries. Along the lower line are specified some of these industries.

Similarly for the lower part of the diagram, there are also two lines : the top line representing various products from the coal and oil, and the second representing some of the general activities depending on the acquisition of the products of mineral resources. The region on the extreme left is supposed to represent trade and commerce connected with the products relating to all these activities.

To the right of the diagram there is a corresponding region representing human labour and the work of man's animal helps, the muscular power which is maintained by the food and the fodder without which none of the activity occurs. Lines are drawn to show where this power operates, in the fields, or the mines. Man's main needs are food, shelter, warmth and clothing. Lines are drawn indicating from where these needs are met. There is also need for water which he gets for very little, and for air which he gets for nothing.

At the bottom right of the diagram, is reserved a place for fuel (got from the mines and oil wells). There is a thick line here so as to indicate that the energy of the fuel not only provides warmth but supplements the muscular energy of man and his animals. There is a line from the centre to the right to indicate that some energy is got from the unstored solar radiation, appearing as hydro-electric power or wind power.

It is very difficult to find satisfactory figures on which to estimate the additional mechanical power available to a worker on account of the energy in the fuel used, because such fuels are employed for providing warmth, for carrying out processes and for power, and most estimates are not worth much. From various figures available I have endeavoured to get an estimate and it seems that each worker in the U.S.A. has the equivalent of about 15 workers to assist him, whereas in Great Britain the figure is about 5. The figures include supplementary power for mechanical work and for transport. It is of some interest that the ratio of the power per worker as between the U.S.A. and the United Kingdom (3/1) is about the same as the ratio of the productivities per head of the two countries.

In India, with a population of 390 millions, the coal production is 25·4 million tons and the power exerted 4,715 million kilowatts. Together they are equivalent to only 0·067 tons per head. In such countries animal power will continue to be the main supplement to man's labour for a long time yet.

Table IV indicates the division of the use of heat and power in the United States and the United Kingdom from which these estimates have been made. For transport in England, we use 16 per cent. of our energy and in the United States nearly double, whereas for domestic heating we use a slightly larger proportion of energy than in the United States.

If I may now go back to the diagram, figures were placed on the diagram to give an idea of the scale of these activities. The value in terms of gold of all upper half activities was estimated to be about four times the total of the lower, and of these activities 88 per cent. was in the production of fuel and fodder, and the rest in the growing of cotton, hemp and all the rest. The production of food was

TABLE IV.

		U.K. %		U.S.A. %	
Domestic Heating		29		20	
Communal Buildings, etc., Heating		2		3	
Transportation	Motor Transport	8	16·5	16	32
	Railways	8		13	
	Coastal Shipping	0·5		3	
Industrial	Power and Heat	40	50	34	45
	Power Stations	10		11	
Miscellaneous		2·5		—	

in fact shown as man's main activity. These figures are taken from Sir Harold Hartley's Mather lecture.

Of the other fifth representing all the activities in the lower half of the diagram 57 per cent. was the proportionate value of all those activities relating to the winning and treatment of the fuels, leaving 43 per cent. for the value of all the other activities along that line.

The value of the products, however, of the lower half activities—the manufactured and engineering goods—was estimated to be double the value coming from the industries along the upper lines from the cultivated products.

Finally there are arrows to represent that people are employed not only in activities involving muscular effort, but also through offices, banks and government departments, etc. in administration and the direction of affairs. A considerable fraction too of labour employed in modern industry and modern agriculture is of course not occupied in exerting muscular power, but rather in exercising skill in controlling machinery which is exerting power, and in directing energy so that it may be used effectively.

With the help of the Intelligence Unit of *The Economist*, I have recently had a check made of the figures. The proportions of the cultivated products for 'food and fodder' and 'raw materials' on 1948 figures, are 86 per cent. and 14 per cent. respectively, while for the 'stored products' the proportions used are 47·3 per cent. as fuel and 52·7 per cent. for manufacturing.

If a diagram like this had been drawn before (say) 1750, the lower part of the diagram would have been insignificant, except for a little trade in metals and for clay and quarried products used for the building trades, brick and pottery ware, and a little 'stored fuel' used for providing warmth, supplementing wood as the main fuel. Transport would have appeared along the lines at the top of the diagram instead of along the bottom. The use of 'stored' fuels has very greatly changed the nature of man's activities.

If the diagram were drawn to scale in terms of energy the region marked 'fuels' would be much larger than that marked 'food and fodder,' but in terms of the money value of the energy the food and fodder should be the larger. The energy in wheat is worth about 20 times as much as that in the form of coal, and 5·5 times as much as the energy of petrol. The amount of food which a worker on the land can produce is generally easily sufficient to maintain a family, but it depends on his implements and on the soil and the sun and on the supplement of work from his animals, or from the energy supplied by fuel. In some parts of the world a family only just keeps itself but in more advanced countries the farm family will feed five other families. However those countries that are far north are at some disadvantage to those more favourably placed, having to provide themselves with more fuel for warmth. There may be some compensation for the extra expenditure, for a cold climate perhaps tends to greater vigour.

The activities at the top left-hand corner of the diagram arise out of the products of the land, cotton from the plant products, leather and wool from the animals, timber from trees—these go to supply the clothing and shelter which

man needs for climatic protection. Many are the industries which arise from treatment of such products—textiles (natural and artificial), plastics, paper, etc. Up to the present, food cannot be produced by the building up process as cheaply as it can be grown. Many syntheses like that of starch or cellulose, or even fats, are best left to nature.

All this activity could have little effect without the means of distribution. The mechanisation of transport has made it all possible. With the advent of air transport came the possibility of greater control of all the activities ; technical help can be brought quickly from one region of the world to another. Perishable products can be conveyed by air transport, or by ship, road or rail in refrigerators and air-conditioned chambers.

The volume of the world's activities are expressed in the huge figures of national incomes. It is of interest to know how many persons there are engaged in all these human activities and particularly in the growing of food. An estimate has been made, on the basis of the figures in the United Nations Demographic yearbook, of the percentage of persons employed in agriculture ; it comes to 48·5 per cent. of the total employed, but that figure does not include the U.S.S.R. and China. Estimates so far as they can be made bring the total of the world's working population in agriculture up to about 60 per cent. Thus it seems true to state that not only in regard to the value of the product of human activity but also in regard to the number of persons employed the production of food and fodder and the cultivation of the soil are still man's main activity.

Take away suddenly the energy which supplements, from fuel and water power, the muscular power of man and his animals, and the modern world would suffer disaster. It might even suffer disaster if the liquid fuel supplies, on which modern transport depends, were suddenly to end without sufficient foreknowledge to make readjustments possible.

In the course of the industrial activities occasioned by the use of supplementary mechanical power, many different things are produced which may also be essential to health and happiness in the modern world, without which civilisation would be defenceless against disease and other impacts of nature. The use of supplementary energy also enables man to enjoy the fruits of the earth with greater ease—with shortened hours of toil in so far as the pressure of the multiplication of the species permits. The energy and food requirements of each part of the world can be assessed with due regard to its particular climate, traditions, industries and the contribution that can be made to the common weal. The satisfaction of the energy needs for warmth, industries, transport and agriculture, can be treated as a local problem as well as a world problem and it involves interdependence.

As President Truman said in his message to Congress at the beginning of 1950 'the Scientific and Industrial Revolution which began two centuries ago has, in the last 50 years, caught up the people of the globe in a common destiny—the human race has reached a turning point. Man has opened the secrets of nature and mastered new powers. If he uses them wisely, he can reach new heights of civilisation, if he uses them foolishly they may destroy him.' Speaking of the United States he said, 'in the last 50 years the income of the average family has increased so greatly that its buying power has doubled. At present the total national production is 255 billion dollars a year ; allowing for the expected growth in population, the real income of the average family in the year A.D. 2000 would be about three times what it is to-day.'

These statements are indications of the state of man's civilisation. But there are of course many backward and ill-balanced regions. Much can be done to arrange more equitable sharing of the advantages that supplies of energy can provide. Not only those who have control of sources of supply should enjoy their benefits. Climatic and topographical circumstances however may compensate to some extent for lack of riches. The goatherd may be as happy as Old King Cole.

The fuel position of the world is to be discussed by Dr. Parker and I will go on to consider the food position which is briefly as follows :—One-quarter of the world's population are up to full nutritional standards and three-quarters are under.

The greater proportion of the food of the world is grown for consumption in the countries where it is grown. The chief problem is to increase efficiency of food production per worker for home consumption. Energy can help in this, mainly by producing fertilisers, insecticides, etc. and equipment for working the land ; also by supplementing mechanically human or animal power. The second problem is to deal with surpluses so that they can help deficiencies.

The population problem is something which it will become necessary to deal with in the future, as the rate of increase is getting too rapid. It must be done by methods kinder and more consciously within the common weal than nature's drastic ways.

The effect of mechanisation on farm operatives is to raise production per worker, and for a given yield less workers are needed. Any surplus of labour presumably is absorbed by the towns and increases thereby urbanisation. The important point is that total productivity per head should be increased. It is not at all certain that increased mechanisation always has a necessary proportionate effect in increased total productivity. Sir Harold Hartley drew attention to the matter when he said that what mattered was the output of goods and services per horse-power employed. I should like to underline that remark.

Another important point is that happiness should ensue, and it is not always a consequence of mechanisation or of easier times and riches. Happiness is derived when the body's muscles and nervous system are in healthy purposeful activity. There is much to be done to ensure that supplemental energy is wisely applied. There are plenty of problems to tackle, but one thing is certain—that wars make the problems more difficult. I summed up the pre-industrial age in the words—food, aggression, and disease. We now in this new era have food, power, much less disease, but aggression is still there. Collaboration for the better integrated use of the world's resources must take its place.

Looking back at the time scale sketched in my introduction, there is need to give thought to man's evolutionary destiny in relation to these energy factors, which are concerned mainly with his material existence. Herbert Spencer a hundred years ago drew attention to the fact that civilisation instead of being artificial is part of nature. Man's brain is certainly unique, but it is a product of natural evolution ; it has provided man with great power of adaptation. A feature of man's progress has been his ' interdependence.' Man has devised for his survival and by his reasoning power means whereby mind could have greater integrated effect—through speech, through the written word, through the printed word. This interdependence has had its effect on the social structure, from the family, through the tribe and the nation, and now towards a world society. That condition may be made possible by the invention of electronic computation which is the most advanced stage yet reached in the series of inventions mentioned which have given effect to man's interdependence. These inventions are the means by which man's brain seeks to supplement its power from the environment which it creates. This is the direction in which civilisation trends. Whether there is ultimate danger in man defeated by his own contrivance, being led by nature to the dead end of non-adaptability, depends on his adaptability, and that can alone be sought within his own individuality.

Interdependence is remarkable in the history of civilisation, but surely far more remarkable is man's own individuality and creative power, as is made plain by the story of ' energy and civilisation.'

MAN'S USE OF SOLAR ENERGY

by

DR. A. PARKER, C.B.E.

INTRODUCTION

WITHOUT the energy received from the sun, human existence and other forms of life on the earth as we know them would be impossible. Not only man's primary needs—air, water and food of the required composition, and warmth, clothing and shelter—but also the secondary material needs to raise the standard of living above mere existence are dependent on the sun's energy and its direct and indirect effects. With the advance in scientific and technical knowledge and skill, man has acquired the power of utilising part of the available energy to raise the material standard of living far beyond what was possible in earlier times. How has this energy been used and what changes and advances are likely in the future? That is the subject of my lecture.

The energy available can be divided broadly into three classes. Firstly there is the energy income being received by direct radiation. Secondly there is energy capital remaining from the store with which the earth when first formed was endowed by the sun, and thirdly capital accumulated by nature's methods of saving a part of the income over various periods of time.

As a first step in considering the subject, it is important to ascertain as nearly as possible the amounts of the capital assets and the income of energy on which we can draw and have in fact been drawing to a greater or lesser extent since the beginnings of life on earth. In what units can these quantities best be expressed? If stated in terms of ordinary units of horse-power or of kilowatts of electricity the figures are so enormous as to be almost beyond understanding. It is proposed, therefore, to use as the principal basic unit the energy equivalent of the heat of combustion of 1 million tons of average British coal. The size of this unit is indicated by the fact that 1 million tons of coal when used with the average efficiency of about 20 per cent. of present-day electricity generating stations can provide 1,600 million units (kilowatt-hours) of electricity, or the equivalent of about 2,150 million horse-power hours.

ENERGY AS CAPITAL

With the unit of 1 million tons of coal as the basis, consider first those capital resources saved from income over long periods of time extending to millions of years, so far as those resources have already been assessed. They include coal (covering anthracite, bituminous coal, brown coal and lignites), petroleum, peat, oil shale and natural gas.

Coals and Lignite

According to the best available information, world reserves of bituminous coals and anthracites are about 5 million million tons, and the reserves of brown coals and lignites are about $1\frac{1}{4}$ million million tons. This gives a total for all coals and lignites of more than 6 million million tons. These figures are definitely conservative. Only those seams have been considered that contain at least one foot thickness of coal or lignite, with a maximum depth below the surface of 4,000 ft. for bituminous coals and anthracites, and 1,650 ft. for brown coals and lignites. Even with these limitations, the estimates are probably low, because many large areas of the world have not been systematically surveyed.

In Table I, figures are given to show how the estimated reserves of more than 6 million million tons of coals and lignites are divided between the continents; figures are also given in this table to show how the world population of about 2,200 millions is distributed among the continents.

TABLE I.

Resources of Coals and Lignites, and Populations.

Continent	Resources thousand million tons			Population millions
	Bit. coal and anthracite	Brown coal and lignite	All coals and lignite	
Europe & U.S.S.R.	1,526	282	1,808	575
N. America	2,081	936	3,017	163
S. America	3	—	3	90
Africa .	203	—	203	158
Asia .	1,080	4	1,084	1,155
Australasia	14	39	53	11
Totals .	4,907	1,261	6,168	2,152

It is interesting to note from the table that more than 85 per cent. of the known coal resources are in the northern hemisphere. This is not so surprising as might at first appear, because nearly three-quarters of the land surface of the world lies in the northern hemisphere. One outstanding point is that one-half of the world resources of coals and lignites is in North America, which has only 8 per cent. of the population and covers only 16 per cent. of the land area. Europe and the U.S.S.R. together, with an area larger than that of North America and a population more than three times as great, have much smaller resources; while Asia, with more than one-half of the population of the world, has less than one-fifth of the total resources of coals and lignites. That is the broad position according to the data so far available; but geological surveys are not nearly so advanced in Asia and some other continental areas as in North America and Europe.

The next step in a review of resources is to consider the data for those countries with substantial reserves, or in which production has been developed to an important extent. For this purpose, the figures for coal resources for a few selected countries are given in Table II, which also includes figures for populations.

The largest share of the world resources of coals and lignites, nearly 3 million million tons or roughly one-half, is in the United States of America. The U.S.S.R. comes next with more than 1 million million tons, and China is a close third. There is then a big drop with Germany fourth at a total of 331,000 million tons, the Union of South Africa fifth at 202,000 millions, and the United Kingdom sixth at 169,000 millions.

Adding together the figures for the resources in those countries in the Commonwealth gives a total for all coals and lignites of about 580,000 million tons. This is only one-fifth of the resources in the U.S.A., or one-half of the resources in either the U.S.S.R. or China, or less than one-tenth of world resources.

Petroleum

Information on the resources of petroleum is much more uncertain than that about coal and lignite. On several occasions during the past 50 years, it has been predicted that at the expected rates of production the oil resources would be exhausted within 15 or 20 years. These predictions have all been incorrect, for though the rate of production has increased more rapidly than expected, new reserves have been discovered as surveys have advanced, and the estimates of resources have been correspondingly increased. In 1937, known resources of petroleum for the world were estimated to be about 4,000 million tons of oil. This is approximately the quantity produced and used since that time; but production still continues at an increasing rate.

According to the most reliable of the recent estimates, the present known reserves of petroleum for the world are about

TABLE II.

Resources of Coals and Lignites and Populations for Selected Countries.

Country	Resources thousand million tons			Population millions
	Bit. coal and anthracite	Brown coal and lignite	All coals and lignite	
U.S.A. .	1,996	838	2,834	141
U.S.S.R. .	982	199	1,181	176
China .	995	1	996	491
Germany .	275	56	331	66
S. Africa .	202	—	202	11
U.K. .	169	—	169	50

13,000 million tons of oil. As the heat of combustion of one ton of petroleum oil is about 1½ times that of one ton of coal, the energy value of 13,000 million tons of oil is equivalent to that of nearly 20,000 million tons of coal. Even so, this is equal only to one-third of 1 per cent. of the coal resources of 6 million million tons.

Of the estimated reserves of 13,000 million tons of petroleum (Table III) 42 per cent. are in the Middle East, 30 per cent. in the U.S.A., 14 per cent. in South America, and 9 per cent. in the U.S.S.R., leaving only 5 per cent. for the rest of the world. The proportion in Europe, excluding the U.S.S.R. is only about 1 per cent., and the amounts discovered in Africa and Australasia are insignificant. Intensive surveys in the United Kingdom have led to the discovery of only very small quantities of petroleum, estimated at about 1 million tons, or enough to meet our needs for only 2 or 3 weeks. The known resources in the Commonwealth are less than 1 per cent. of world resources.

TABLE III.

Petroleum Resources.

Country or Area	Resources	
	Millions of tons	Per cent. of total
Asia—Middle East	5,571	42·4
Asia—Far East	289	2·2
U.S.A.	4,000	30·5
Mexico	139	1·1
Canada	41	0·3
Venezuela	1,536	11·7
Colombia	83	0·6
Argentina	46	0·4
Trinidad	39	0·3
U.S.S.R.	1,214	9·2
Roumania	68	0·5
Other countries	107	0·8
World total	13,133	100·0

Peat

Though there are large deposits of peat in many parts of the world, there have been few systematic surveys of the area and thickness of peat bogs with the object of assessing the quantities available for use as fuel. As it occurs in the bogs peat contains 90 to 95 per cent. of water; before it can be used much of the water has to be removed. The recorded probable reserves in Europe in bogs of a minimum thickness of 20 in. are equivalent to about 110,000 million tons of peat containing 25 per cent. of moisture; and the corresponding reserves in the U.S.A. are equivalent to about 12,000 million tons. The total recorded reserves of 120,000 million tons (Table IV) must be much smaller than the true quantity, as there are no data for vast areas containing large quantities of peat. As the calorific value of peat with 25 per cent. moisture is only one-half of that of coal, 120,000 million tons of peat is equivalent to only 60,000 million tons of coal, or about 1 per cent. of world reserves of coals and lignites.

TABLE IV.

Recorded Resources of Peat.
Millions of Tons at 25 per cent. Moisture.

Country	Resources
U.S.S.R.	71,190
U.S.A.	12,345
Germany	9,840
Sweden	8,860
Poland	5,900
Eire	3,450
Finland	3,450
Estonia	2,000
France	1,970
Latvia	1,640
Other countries	974
Total	121,619

There are large areas of peat bogs in the United Kingdom, not included in Table IV, but they have not been systematically surveyed. It is probable that the total quantity in the United Kingdom is equivalent to an amount of the order of 10,000 million tons of peat containing 25 per cent. moisture. A survey has been begun of the peat bogs in Scotland.

Oil Shale

In many parts of the world there are large deposits of oil shales and similar materials, which on heating or distillation yield oil. As the resources in general have not been systematically surveyed the available data are far from complete.

According to the estimates that have been made, world resources of oil shale are at least 470,000 million tons, from which not less than 22,000 million tons of oil could be obtained. Of this estimated reserve of shale oil, three-fifths is in the U.S.A. and one-third in the U.S.S.R. The oil-shale resources of the United Kingdom are sufficient to provide only about 70 million tons of oil. It is worthy of note that the recorded reserve of oil in the oil shales of the world is nearly twice the present estimated reserve of petroleum oil.

Natural Gas

Combustible hydrocarbon gases, mainly methane or fire-damp, are always associated to a greater or less extent with underground reserves of oil and coal.

From experience in the petroleum industry, it has been estimated that on average the quantity of natural gas associated with each ton of oil is in the region of 15,000 cu. ft., or a volume with an energy value of about 40 per cent. of that of the oil. On this basis, the estimated reserves of oil of 13,000 million tons would be accompanied by gas equivalent to an additional 5,000 million tons of oil, or about 7,500 million tons of coal

It has been estimated that in the production of coal in Great Britain, the energy value of the methane gas released is roughly 1 per cent. of that of the coal obtained. If it is assumed that the proportion of methane is the same for all coal measures, then the reserves of methane in the estimated world reserves of coal would be equivalent to about 60,000 million tons of coal.

Atomic Energy

With the limited knowledge and experience so far obtained, it is impossible to give any reasonable estimate of the resources of materials that might be used in harnessing nuclear energy from atomic fission, though surveys of such materials as uranium ores are in progress in many areas.

Terrestrial Heat Energy

There is an enormous reservoir of energy in the form of sensible heat remaining in the earth from the energy with which the earth was originally endowed by the sun. It has been estimated as equivalent to the heat of combustion of 500 trillion (million million million) tons of coal, or 80 million times the estimated reserves of coal.

Total Energy as Capital

From the information so far considered figures are given in Table V to show the capital energy resources of the world in the form of the 'fossil' fuels—coals and lignite, peats, oils and natural gases. The estimated reserves of all these fuels together are equivalent to about 6 million million tons of bituminous coal. Of this quantity, 97 per cent. occurs as coals and lignites, 1 per cent. as peat, 1 per cent. as gas, and less than 1 per cent. as oil or oil-bearing shale. Though the amount of terrestrial heat energy is enormous in comparison, it is not included because it is mostly at such great depths as to be inaccessible by any methods likely to be developed in the foreseeable future.

TABLE V.

Capital Energy Resources of the World Fossil Fuels.

Resource	Thousand million tons	
	Quantity in Reserve	Bituminous coal equivalent
Coals and lignite . .	6,168	5,850
Peat (25 per cent. moisture) .	122	61
Methane gas in coal measures	—	60
Oil in oil shale . . .	22	33
Petroleum	13	20
Natural gas with petroleum .	—	8
Total of fossil fuels . .	—	6,032

ENERGY AS INCOME

It has been estimated that the sun, which is the primary source of the energy available to the earth, is radiating energy at a colossal rate equivalent to the heat generated by the combustion of more than 10,000 million million tons of coal every second, and that at this rate its stock of energy would be sufficient for 10 million million years. Of this energy, only one part in 2,000 millions reaches the earth and its atmosphere ; and of the quantity

received a large proportion, of the order of nine-tenths, is radiated or reflected back into space. Even so, the energy received by the surface of the earth from the sun is equivalent to the heat of combustion of 17 million million tons of coal a year, or about 8,000 times the heat of combustion of the coal and petroleum produced and used annually at the present time. This is an enormous income of energy received as heat, light and electricity which are used by nature's methods to provide vegetation and animal life, and movement of air and water. Part of the vegetation and animal life has been converted and stored over thousands or millions of years to provide the capital assets in the form of coals, lignite, oil, peat and natural gas already discussed.

It is now intended to consider the forms of energy income, which cover energy collected over periods less than a few hundred years, that is periods in the life of the earth comparable with the frequency of payment of wages in man's span of activity. These forms of energy income include not only direct radiation from the sun, but also wood, food, water power, and wind power.

Wood

The forested areas of the world cover about 15 million square miles, or more than one-quarter of the total area of land. These areas are divided over the continents as shown by the figures in Table VI.

TABLE VI.

Forested Areas of the World. Millions of Square Miles.

Continent	Area
Europe and U.S.S.R.	4·0
N. America	2·8
S. America	2·9
Africa	3·3
Asia	2·0
Oceania	0·3
Total	15·3

As a rough overall average, it can be taken that each square mile of forest could provide 15,000 to 20,000 cu. ft. of wood per annum. On this basis 15 million square miles should provide about 250,000 million cu. ft. per annum. The whole of this quantity should not be counted as fuel, as much of it would be timber suitable for constructional work. It is reasonable to assume that rather more than one-half —say 150,000 million cu. ft. per annum— could be made available as fuel. This quantity would be equivalent in energy value to the heat of combustion of about 1,000 million tons of coal a year.

Water Power

According to recent estimates, the potential annual production of electricity from non-tidal water power is more than 6 million million kilowatt-hours. To generate this quantity of electricity from coal-fired steam stations with 20 per cent. efficiency would require more than 3,500 million tons of coal a year, or nearly three times the present annual production of coal. Great Britain possesses only a fraction of 1 per cent. of this total world potential.

It has been estimated that the power corresponding to the dissipation of the energy of the tides is 1,000 million kilowatts. This is equivalent to the thermal energy of combustion of 1,000 million tons of coal a year.

Wind Power

According to one estimate, the world resources of wind power that might be used could provide 13 million million kilowatt-hours of electricity every year. To generate this quantity of electricity at 20 per cent. efficiency at power stations burning coal would require about 7,500 million tons of coal a year.

Food

On average, the thermal value of the food required by the population is about 12,000 B.Th.U. per person per day. With a population of 2,200 millions, the total world requirement of human food is nearly 100,000 million therms a year, equivalent to the heat of combustion of about 320 million tons of coal a year. In addition, there is the food taken by numerous animals, wild and domesticated, and there is much waste in preparing food. With these additions, the energy equivalent of all the food material must be in the

region of the heat of combustion of 600 million tons of coal a year.

Energy Capital and Income

The data already discussed show that the amounts of energy within the earth and being received by the earth from the sun are colossal. Energy in the form of sensible heat within the earth is equal to the heat of combustion of 500 trillion (million million million) tons of coal, and it is known that the store of the fossil fuels within 4,000 ft. of the earth's surface is equivalent to at least 6 million million tons of coal. As income, the earth is receiving from the sun energy equal to the heat of a combustion of 17 million million tons of coal every year. But in the present state of knowledge, it is not possible for man to harness more than a minute fraction of all this energy. That fraction includes the fossil fuels, wood, water power, wind power, and foods to the amounts shown in Table VII. In addition, it is possible to harness relatively small amounts of energy from the sensible heat of the earth's crust and from the radiation received from the sun.

Table VII.

Available Energy—Capital and Annual Income in Coal Equivalents.

Energy resource	Coal equivalent thousand million tons
Capital	
Fossil fuels .	6,032
Income	
Wood . .	1·0
Water power .	1·7
Wind power .	1·5
Foods . .	0·6

According to the figures in Table VII, it is possible in the present state of knowledge to draw on a capital equivalent to 6 million million tons of coal, and an income equivalent to about 5,000 million tons of coal a year. It should be pointed out, however, that with the methods as so far developed, the costs of harnessing and utilising more than one-half of the fossil fuels and more than one-fifth of the total income of energy shown in Table VII would be prohibitive. Even so, this leaves available capital equal to 2 or 3 million million tons of coal, and income equal to about 1,000 million tons of coal a year.

Energy Utilisation

Following a survey of energy resources the important question is how they are being used. Until a few hundred years ago, before the Industrial Revolution, the principal fuel for heating was wood, with water power and wind power to assist the labour of men and animals. Within the last 250 years, a very short period in the history of man, there have been remarkable developments in the use of fossil fuels for the production of heat, light and power. These developments have had a profound effect on the ways and standards of life and on human affairs generally.

As an example, consider the changes that have taken place in Great Britain during this period as a result of developments in the use of coal. Though coal has been used in Great Britain as a source of heat for at least eight centuries, the amount used before the nineteenth century was small. In the year 1700, annual production was only 3 million tons for a population of 6 or 7 millions. Early realisation of the possibilities in the use of coal for the generation of heat, light and power, combined with the skill and enterprise of our engineers and industrialists of the eighteenth and nineteenth centuries, then gave Great Britain a good lead in the mechanisation and industrialisation that followed. Great Britain was fortunate in having large reserves of coals of good quality. By the year 1800, the annual output of coal had been increased to between 10 and 15 million tons, and the population had risen to 10 or 11 millions. Then began the great acceleration in the growth of industry until, by the year 1900, the output of coal was about 220 million tons a year, the population had reached 37 millions, and the country had definitely moved over to dependence mainly on industry instead of on agriculture.

Towards the end of the nineteenth century, industrialisation had begun to spread rapidly to some other countries

with good reserves of coal, especially in Europe and America. In consequence our lead was becoming less pronounced, and overseas competition was increasing rapidly.

Since 1900, scientific and technical advances have been so rapid that they seem to have outstripped the capacity of man to organise the use of this new knowledge for the maximum common benefit. Advances during this short period have included great improvements in internal combustion engines using oil for transport by land, sea and air ; the development of the gas turbine and the jet engine for high-speed aircraft ; great increases in the efficiency of boilers and steam turbines for the generation of electricity on a scale many times greater than at the opening of the twentieth century ; and a substantial increase in the use of water power.

All these advances, with improvements in agriculture and in other directions, have enabled the world to support an increasing population at a higher average standard of living. In Great Britain, the population has risen since the year 1900 by about 13 millions to the present-day figure of 50 millions. World population has increased to about 2,200 millions, and the annual rate of increase is now about 20 millions.

So far, the energy used to supplement the labour of men and animals has been derived mainly from the combustion of coal and petroleum. It has been estimated that, since the beginning of historical records, 85,000 million tons of coal and nearly 10,000 million tons of petroleum have been used. But the outstanding facts are that, of these quantities, one-half of the coal produced has been use within the last 30 years, and one-half of the petroleum during the last 10 years.

The rates at which coal and petroleum are now being used are very great in comparison with the rates of accumulation—so great that the position is similar to that of a nation saving a part of its income every year, for, say, a hundred years, and then spending the accumulated capital so rapidly as to exhaust it in a few days. If this is the position, there will eventually come a time when the reserves of fossil fuels will be exhausted and mankind will be compelled to obtain energy from resources more difficult to harness and distribute. It is important, therefore, to consider the rates at which the fossil fuels are being used.

During the past 25 years world production of coals and lignite has fluctuated over the range of 1,100 million to 1,700 million tons a year, with changes in trade activity and other factors. There has been no marked trend over this period either upwards or downwards in rate of production for the world as a whole ; and the overall average rate has been about 1,400 million tons a year. Rate of production of petroleum, however, has increased rapidly over the same period from about 150 million tons to 500 million tons a year ; and the production and utilisation of natural gas has increased relatively more rapidly until it is now about 6 million million cu. ft. a year, mostly in the U.S.A. The recorded annual production of peat is about 16 million tons, equivalent to 8 million tons of coal or little more than 0·5 per cent. of the quantity of coal produced annually. World production of shale oil is only about 400,000 tons a year.

Coals and Lignite

The world reserves of coals and lignite at approximately 6 million million tons are about 4,500 times the present annual production. It is certain, however, that it would neither be practicable nor economic, under any conditions that can be foreseen, to work the whole of the known reserves. Underground waters, faults in the strata, and other factors would in many instances cause serious difficulties and entail abnormally high costs. In some countries, including Great Britain, the most easily accessible seams have already been exploited to a considerable extent ; and the difficulties in maintaining production at reasonable cost are increasing. Allowing for all these factors, it seems reasonable to conclude that for the world as a whole the known reserves of coals and lignite that could be worked economically should be sufficient for 2,000 years at present rates of production. In addition there is a margin in the resources not yet discovered It must be emphasised however, that the reserves are not

uniformly distributed geographically or in relation to population and needs; and they are by no means being uniformly exploited. Adopting the same general basis as in estimating the life of the resources of coals and lignite for the world, the resources in the U.S.A. should be sufficient to maintain production in that country at 500 million tons a year for at least 2,000 years. The position is similar in the U.S.S.R. with a rate of production of about 200 million tons a year. In Germany, East and West together, the reserves should be sufficient to provide the pre-war rate of production of about 300 million tons a year for at least 400 years. With regard to Great Britain, there is sufficient workable coal for the next 200 years at an annual production of 250 million tons. As in some other countries, however, it is important to ensure that coals of particular types, such as good coking coals, are allocated to the uses for which they are specially suitable and not squandered for purposes for which other, more plentiful, coals could be satisfactorily employed.

Petroleum, Natural Gas, and Shale Oil

Recorded resources of petroleum and of the natural gas associated with the oil are no more than 25 times present annual production. Though new resources will almost certainly be discovered, there is little doubt that the true reserves are small in relation to coal resources; and it seems probable that there will be difficulty within the next 50 or 100 years in meeting world demand for petroleum oils. As the resources of petroleum become depleted, it may be necessary greatly to extend the production of oil from oil shale, though at greater cost. Known resources of oil shale could provide 500 million tons of oil a year for at least 40 years. There are also synthetic processes of making oil from coal, but in general at a cost very much greater than that of winning and treating petroleum.

Peat

Peat resources have hardly been touched in most areas, particularly where supplies of coal or oil are available at reasonable cost. The recorded world production of 16 or 17 million tons a year includes nearly 6 million tons in Denmark, 5 million tons in Eire, and 2 million tons in Poland; figures are not available for the U.S.S.R. At this rate, the known resources would last for 7,000 years; but the annual production is equivalent to no more than 0·5 per cent. of the coal produced.

Wood

Though the forested areas of the world cover 15 million square miles, only 5·5 million square miles, or about one-third, are considered to be productive forests in accessible areas. Estimates of world consumption of wood during the ten pre-war years indicated an annual rate of 53,000 million cu. ft., of which 30,000 million cu. ft. were used as fuel, equivalent to about 200 million tons of coal a year. It is interesting to note that the net annual rate of growth in the forested areas of the U.S.A. is about 12,000 million cu. ft., which is several times as great as for any country for which records are available. It is 260 times as great as the figure of 45 million cu. ft. for Great Britain. Separate figures are not available for the U.S.S.R., but the area under forest in that country is much greater than in the U.S.A.

Water Power

Plant installed for generating electricity from non-tidal water power has a capacity of about 70 million kilowatts, or 4 per cent. of the estimated potential water power at mean flow. In Great Britain in 1947, the total quantity of electricity generated was nearly 43,000 million kilowatt-hours, of which 1,200 million kilowatt-hours or nearly 3 per cent. was from water power.

It is only in a few areas that the range of tide is sufficient to consider justifying harnessing the power. Within the last 25 years, tidal-power schemes with a total estimated annual production in the region of 10,000 million kilowatt-hours have been considered in detail; but the schemes have not been developed, mainly because the costs would have been too great.

Wind Power

Though the energy of the winds has been used for centuries in small units of

a few horse-power, no large units have been constructed to harness the power for general use. The reasons for this lack of development have been the high capital costs, and the variations and uncertainties of wind velocities. The possibilities are now being reconsidered, and experimental generators of capacities up to 800 kilowatts have been built in the U.S.A. and U.S.S.R. Experimental work is in progress in Great Britain ; and a windmill to generate 100 kilowatts is being installed in the Orkneys.

Terrestrial Heat Energy

Terrestrial heat is collected and utilised in a few areas where it reaches the surface as geysers or hot springs ; and work is in progress on extracting heat energy by means of heat pumps. It is unlikely, however, that in the near future there will be any substantial extension in utilising terrestrial heat.

Solar Radiation

Radiation from the sun has been used direct in some parts of the world, for example in evaporating solutions of salt and in providing hot water for houses. Only in unusual circumstances, however, is it likely that such systems could compete with nature's method of photosynthesis through vegetation.

Vegetable and Animal Wastes

There are numerous vegetable and animal wastes that could be, and are to a small extent, used as fuel for the generation of heat and power. In general, materials of this kind are bulky and associated with large quantities of water.

In consequence costs of collection, transport, drying, and utilisation are usually prohibitive in relation to their fuel value. Examples of such waste materials being used as fuel to a small extent, at the points of production or where costs of collection are low, are sawdust and wood shavings, town refuse, sewage sludge after drying, and, in some tropical areas, animal dung.

Reference should also be made to the production of fuel alcohol and methane gas by the fermentation of vegetable and animal wastes and by-products. As a rough estimate, annual world production of alcohol before the war was equivalent to 3 million tons of absolute alcohol. Of this total less than one-fifth was used as fuel. This means that the fuel alcohol was equivalent to no more than 0·5 million tons of coal a year. Since 1939, production of alcohol for fuel has declined. If required, more could be made, but at a high cost in comparison with the price of petroleum.

At several sewage disposal works methane gas from the fermentation of sewage sludge is being collected and used. Experience has shown that, on average, the quantity of gas that can be obtained in this way is about 1 cu. ft. per day for each person served by the sewage works. The process was first developed on a large scale at the works of the Birmingham, Tame, and Rea District Drainage Board, where the gas is used to provide much of the power required at the works. This lead has been followed at a number of large sewage works in Great Britain and abroad. It is only at comparatively large works that it is economic to install and operate the equipment necessary to collect and use the gas. The total quantity of sewage-sludge gas produced in Great Britain is in the region of 1,000 million cu. ft. a year, equivalent in thermal value to about 25,000 tons of coal a year.

Food

It has already been mentioned that the thermal value of the food required by the world population is equivalent to the heat of combustion of about 320 million tons of coal a year ; and that the energy equivalent of all the food material must be in the region of the heat of combustion of 600 million tons of coal a year.

Total Energy Utilisation

In Table VIII, the information given on energy utilisation is tabulated to show the world annual consumption of the different forms of fuel and energy in terms of coal equivalents.

Of the total consumption, equivalent to rather more than 3,000 million tons of coal a year, 10 per cent. is as food for the people, 41 per cent. as coals and lignite, 22 per cent. as petroleum, 6 per cent. as natural gas, 6 per cent. as wood,

5 per cent. as water power, and 1 per cent. from miscellaneous sources.

TABLE VIII.

World Annual Consumption of Fuel and Energy Expressed in Coal Equivalents.

Fuel or energy	Coal equivalent million tons	Per cent. of total
Food for population	320	10
Food for animals, etc.	280	9
Coals and lignite	1,330	41
Petroleum	700	22
Natural gas	200	6
Wood	200	6
Water power	165	5
Peat, shale oil, etc.	45	1
Total	3,240	100

In general, those countries with the greater fuel and energy consumptions in relation to size of population have the higher average incomes, indicating the importance of supplies of energy to supplement man-power, if high standards of living are to be maintained. In comparison with the world average of the equivalent of between 1·4 and 1·5 tons of coal per person annually, the figure for the U.S.A. is now over 8 tons, while that for Great Britain is little more than 4 tons. In countries such as India and China it is less than 0·5 ton. It is not surprising, therefore, that the U.S.A. is relatively so prosperous.

EFFICIENCY OF UTILISATION

It has been estimated, as a rough average, that the thermal value of the food required by the population is 12,000 B.Th.U. per person per day. To maintain human health and energy, many other factors in relation to food, in addition to thermal energy, must be taken into account. As a kind of base line, however, consider first the work output that can be obtained by manual labour. A labourer turning a winch for eight hours can do useful work equal to 0·6 horse-power hour, which is equivalent to between 1,500 and 1,600 B.Th.U., or about 13 per cent. of the thermal value of his food. With other forms of manual work the corresponding efficiency may be a little higher, or it may be much lower.

Though there have been great advances in science and technology within the last 50 years, the overall average efficiency of utilisation of fuel and power resources is well below 20 per cent. There is thus great scope for improvement ; and there must be determined efforts to this end, if waste is to be reduced, and more power is to be made available without an unduly rapid depletion of those fossil fuels that are most easily accessible. Unless there are improvements in face of the slowly increasing difficulties, it will not be easy to raise the standard of living, or even to maintain the standard.

From the information given in this lecture, it might be concluded that the total resources of the fossil fuels—coals and lignites, petroleum, oil shale, natural gas, peat, and possibly atomic energy—are sufficient to meet the needs of the world as a whole for many centuries ; and that when these resources are exhausted there is sufficient energy available in the form of income to satisfy requirements so long as the world is inhabited. A broad conclusion of this kind would give a false measure of the situation. Before these resources can be utilised, they have to be garnered, harnessed, distributed and changed in form by methods and processes requiring labour, materials and the dissipation of energy. Further, the resources are not evenly distributed in relation to requirements. In spite of the vast resources, there are many large areas in which the energy desired cannot yet be provided economically, and where there are acute shortages of fuel. Every technical advance towards improving the overall efficiency of collecting, harnessing, and distributing fuels and forms of energy increases the availability locally and over a larger area.

ENERGY IN THE SERVICE OF MAN

It has been mentioned that in the U.S.A. where fuel and energy utilisation is higher than in any other country, the quantity per person per year is equivalent to more than 8 tons of coal. Of this quantity rather more than one-third is used for providing warmth, hot water, and cooking

in homes and other buildings, leaving the equivalent of 5 tons or 1,400 therms for power, transport and industrial processes generally. Assuming that the 1,400 therms as fuel is used with about the same overall efficiency as that possible with food as a fuel in providing manual labour, the 1,400 therms can be considered as providing each individual with more than 30 servants to assist him in meeting his needs. Great Britain comes next with the equivalent of a little more than 4 tons of coal a year, of which about half is for warmth, hot water and cooking, leaving about 2 tons for power, transport and industrial processes. This is equivalent to providing each individual with 13 or 14 servants. Take these servants away or employ them less efficiently, and the standard of living must fall.

There is no doubt that the comparatively high standards of living attained in the U.S.A. and Great Britain have been built up largely on the availability of fuels and on the ingenuity, skill and enterprise of scientists and technicians. Until recent years, the fuels have been cheap, and there has in consequence been much waste. It is unlikely that they will ever again be relatively so cheap. Not only for this reason, but in the interests of conservation and the need for more energy to raise the average standards of living, waste must be cut down and there must be continuous striving towards greater overall efficiency. Here is an enormous and important field for research and development work which the world cannot afford to neglect. Scientific and technical advances will undoubtedly be made, which can raise the standards of living provided that the knowledge acquired is applied in the right direction. Will the moral standards of the human race rise so rapidly as material knowledge to ensure that the increased power is used in the right directions? That is the important question of the age.

Conclusion

What is the lesson for Great Britain? This country was the first to realise the value of fuel and power and to use her native ingenuity and skill in exploiting her coal resources in the development of industry.

Other countries with good coal resources then followed, and the U.S.A. not only began to use her vast reserves of coal, but was also the first to exploit her petroleum reserves. In consequence competition has steadily increased. In course of time, countries that are still backward will begin to develop and competition will be further intensified. National ability, skill and hard work will then begin to play an even greater part in achieving success.

For many years the prosperity of Britain will be dependent largely on the utilisation of our main asset, coal, with the greatest possible efficiency, combined with high efficiency in all our activities, in industry, trade and agriculture. On the basis of existing knowledge, we could save many millions of tons of coal a year without any reduction in the useful heat and power obtained, and with much less pollution of the atmosphere by smoke. Better still, we could increase industrial productivity with some reduction in costs by obtaining larger quantities of useful heat and energy from the same amount of coal.

With our dearth of indigenous petroleum, there must be determined efforts to devise methods of making oil from coal at reasonable cost, and of using coal directly or indirectly to take the place of oil for many purposes.

With our native talent, success can be achieved provided our activities are based on a foundation of adequate scientific and technical knowledge, research and development work. The price of success is hard work, vigilance, sound judgment, with avoidance of all unnecessary waste, whether of man-power or material.

POWER, ITS PRODUCTION AND DISTRIBUTION

by

JAMES R. BEARD, C.B.E.

MAN's progressive discoveries of the means of using power are the history of the material aspects of our civilisation and have been described by Sir Alfred Egerton. The ways in which solar energy is used to-day has been the concern of Dr. Parker. I propose, therefore, to concern myself with the problems of electric power.

Electric power is often talked about as if it were a fundamental form of power in itself. Actually the only way in which it occurs in nature is in the form of static electricity in the clouds and, so far from being useful, its occasional discharge—lightning—has always been one of the bugbears of the electrical engineer. Electric power produced from mechanical power (or occasionally on a small scale from chemical power) has only a transitory existence and is almost immediately reconverted into mechanical power or into light, heat or chemical energy.

It has achieved its present great importance in our twentieth-century civilisation because it possesses to a unique degree the three qualities of ease of distribution, application and control. These enable mechanical power to be produced under the most favourable economic conditions and, after being transmitted as electrical power, to be eventually used in the required quantities and form exactly where it is needed.

Ease of distribution is due to the fact that electricity can be transmitted in either large or small quantities for considerable distances with very little loss and over a relatively cheap transmission system. Starting about 1880 with distributing a few hundred kilowatts at one or two hundred volts over perhaps one or two square miles we now distribute hundreds of thousands of kilowatts at 132,000 volts over thousands of square miles.

Ease of application is equally important, starting with the sub-division of the electric light, as it was called in the 1880's, the range of application now stretches from tiny machines driving a razor to the most powerful locomotives, rolling mills and steel furnaces. In between lie the domestic applications to cooking, cleaning and refrigeration, and the industrial applications to driving all kinds of machines and providing all kinds of heating in our modern factories. The electric motor is small, compact and self-contained so that it is increasingly being incorporated in the machine it drives. Electric heating can be applied exactly where heat is required, needs no air and produces no fumes.

Ease of control has contributed much to these applications. Not only can electricity be turned on and off in any quantity by the manipulation of a tiny switch or push button but its intensity can be readily varied and—most important of all—electric motors can be constructed for any desired speed and, when this is necessary, can be constructed to operate over a wide range of speed.

These advantages of electric power have no doubt played a part in the absolute increase of power per productive worker which has been such a marked feature in recent years. They have also enabled the earlier use of power to be made more efficient.

What is this electric power industry and how has it developed? To-day the electrical industry comprising the production and distribution of electricity and the manufacture of the plant to produce and use it, has become the third largest in the country—following agriculture and mining. This has all happened within the lifetime of many still alive and the greater part within the lifetime of most people. It began in 1878 surprisingly enough in Godalming when the first public electricity supply cables were laid in the gutters to give a supply throughout

the town from a central power station to the newly invented incandescent carbon filament lamps. Similar small undertakings sprang up elsewhere and it quickly became apparent that some control of these was necessary and that the undertakings themselves needed certain statutory powers. At that time no one visualised supplies outside urban areas or over more than a few square miles. It was, too, the time when there was growing enthusiasm for municipal trading in which Birmingham had led the way. As Joseph Chamberlain was then President of the Board of Trade it was very natural that the new legislation provided that any powers granted to a company should eventually be transferable to the local authority. Thus from the very beginning electricity supply visualised eventual public ownership and the first steps were taken by that distinguished Birmingham citizen. The 1882 Act started a long succession of legislation which has lasted up to the present day. The early Acts were all called Electric *Lighting* Acts and the systems were operated by electric *lighting* companies or electric *lighting* committees but by the turn of the century the idea of distributing at high voltage over wide areas for industrial power purposes had taken root and powers were given under electric power Acts to a number of companies covering the chief industrial areas.

Electric *power* distribution is just 50 years old, the first public power supply system being inaugurated on Tyneside by Lord Kelvin in June 1901. In sketching the early developments in generation and distribution of electric power I propose to use the North-East Coast as a background because during the first 20 years of this century most of the pioneering work in this country was done there.

There were two main reasons for this pre-eminence. The first was that to a considerable extent the urban areas on the North-East Coast were integrated with the wider power supply areas under the leadership of a company which had started with powers for the largest city in the neighbourhood—Newcastle-upon-Tyne—as a basis, whereas in the rest of the country the other power supply companies went through a very difficult period because the urban loads in industrial areas were already largely supplied by municipally owned undertakings and were excluded from the areas of supply of the power companies. The other reason was the initiative and foresight of the late Charles Merz and his colleagues who fortunately found ideal scope for their energies. I myself was a humble participant from 1905.

The original electric *lighting* station of the Newcastle Company at the end of last century consisted of Robey engines about 175 kW., steam pressure 120lb./sq. in.

Neptune Bank, Wallsend, was the first station built specifically for three-phase power supply and was opened by Lord Kelvin. As was the fashion in those days it was equipped with slow-speed marine engines of 800 kW., boiler pressure of 200 lb./sq. in. and no superheat. The station was soon extended by the first 1,500 kW. turbine in the world to be put into commercial service. Sir Charles Parsons' development of the turbine took place on Tyneside and Merz took full advantage of this and closely worked with Parsons on turbine plant for power station work.

The next stage in 1904 was the construction of the Carville Station on a large riverside site on the Tyne at Wallsend. This eventually housed eight 4,000 kW. turbo-alternators, the steam pressure being 200 lb./sq. in. with superheat. This station was in many ways a landmark in power station design as was the *Mauretania* in liner design. They were built about the same time alongside each other. In 1910 a new site was developed on the Tyne at Dunston to the west of Newcastle on somewhat similar lines but with sets of about twice the size.

Three years later a great advance was made by the construction of the Carville B Station for which the then very high steam conditions of 275 lb./sq. in. and 700° F. were adopted together with 11,000 kW. turbo-alternators running at the then unheard-of speed of 2,400 r.p.m. with water-cooled rotors. This station established a record for thermal efficiency which it held for a number of years.

This was followed in 1917 by North Tees, a most striking station in the southern part of the area in which Merz

gave practical trial to Ferranti's proposal for re-heating the steam during expansion, a method which has since been widely used in the U.S.A. for stations designed for high efficiency. The North Tees Station also gave practical trial to another suggestion which Ferranti had emphasised, even if he were not the first to put it forward, that the efficiency of the cycle might be improved by bleeding steam during the process of expansion for the purpose of heating the feed water. This depended upon useful application being made in other directions of the heat in the flue gases which for many years past had been commonly used for feed water heating and the solution was to use this to heat the incoming air for the furnaces. This development is one which is universally used to-day. At North Tees also the size of the set was increased to 20,000 kW. at 2,400 r.p.m. and the steam pressure at the turbine to 450 lb./sq. in.—all rather revolutionary in those days. For a while North Tees held the lead in thermal efficiency but its main interest is as a prototype and on it was based much of the development in American power station design.

The next and at present the latest stage of development on the North-East Coast was a new station on the Dunston site—Dunston B—which is equipped with 50,000 kW. units with steam conditions of 600 lb./sq. in., 800° F. and re-heat.

While I am not suggesting that the North-East Coast had any monopoly of power station development during the first quarter of the century and in fact much good work was done elsewhere it was, I think, exceptional when viewed as a whole and redounds to the credit of British engineering.

So much for generation on the North-East Coast but there was parallel development there on the transmission systems which were to distribute the power from these large stations to the shipyards, mines and other industries. Ferranti had given the lead in solving the problem some years earlier by his underground 11,000 volt transmission from Deptford to London and by the end of last century the manufacture of paper insulated cables started by the British Insulated Cable Company at Prescot was well established for voltages up to 11,000. Actually only 6,000 volts was used on Tyneside to begin with but when the problem of distributing electricity throughout the coalfields in Northumberland and Durham was tackled in 1906, it was realised that something much higher was needed. At that time Germany was considerably in advance of this country in the development of high voltage transmission and based on their experience it was decided to lay down a 20,000 volt cable network, the first cables, transformers and switchgear of which were supplied by the A.E.G. However, as quickly as possible British manufacturers were encouraged to develop similar plant which they successfully did. First attempts were also made to cheapen transmission by the use of overhead lines but for some years progress was very slow due to the unduly high factors of safety and restrictive precautions insisted upon by the Board of Trade and the absence of any effective method of overcoming wayleave difficulties. Perhaps the most important contribution on the North-East Coast to high voltage distribution problems was the invention of the Merz-Price balanced protective gear which ensured that a cable would only be switched out when it was faulty in itself and not by faults passing through it to other parts of the system. This was the forerunner of the many complicated protective systems of the present day. It made an epoch-making change in the lay-out of high voltage systems enabling what is called an interconnected lay-out to be adopted in which a ring main fed at both ends is tapped at many points for giving duplicate supplies. Another contribution was the metal-clad switchgear which was developed by Reyrolle at Hebburn.

Up to World War I the various electrical undertakings, the greater proportion of which were municipal, developed fairly rapidly but on the whole continued self-contained and isolated. The power companies serving the wider areas outside the towns were having a hard struggle apart from the special case of the North-East Coast but they finally established themselves on a sound basis when the power requirements of the munition factories established during the war brought out the national importance of a generally

available supply of electricity and the inherent weaknesses of the rather parochial systems of that time. Even before the war ended consideration was being given to some form of overall national control of the industry in order to promote its orderly development, the idea at that time being that the country should be split up into a number of areas similar to the North-East Coast. As a first step Electricity Commissioners were appointed to prepare and initiate schemes but their powers were too restricted with the result that their efforts were largely frustrated by the jealousies of the different existing undertakings. The ineffectiveness of the Electricity Commissioners' efforts led Mr. Baldwin in 1925 to set up a small Committee under Lord Weir and its report was the beginning of the development of electricity in this country on proper co-ordinated national lines. The Committee showed its wisdom by bowing to the political impossibility at that time of forcing the amalgamation of existing undertakings but put forward proposals for achieving most of the benefits of such amalgamation as far as generation was concerned by the establishment of a very high voltage system to link up the larger power stations and to supply in bulk the small undertakings who could not generate so cheaply as the larger ones. They christened this system the *Grid*. The name caught the popular imagination and has since been generally used not only for our British system but overseas. In fact, almost the first wish of any newly developing country is to have a grid whether or not conditions are ready for it. Unlike most committee reports this one was speedily implemented by the 1926 Act setting up the Central Electricity Board. Starting with much antagonism from existing undertakings it was most wisely guided from the start by its first Chairman, Sir Andrew Duncan and its first General Manager, the late Sir Archibald Page. Their efforts were rewarded by increasing co-operation from the undertakings and a sympathetic reaction of the public to the rather novel feature of the 132,000 volt Grid transmission lines in the countryside.

A factor which did much to ensure the success of the Grid was the decision to standardise 50 cycles throughout the country—a decision largely due to the courage of Sir John Snell, the Chairman of the Electricity Commissioners. It involved an expenditure of £17 million. This seemed a large sum in those days particularly as the return on it was difficult to assess and not immediate. But looking back over 25 years no one questions the wisdom of the decision.

The major functions of the Grid were two-fold. First it enabled the spare generating plant provided by each undertaker in his own station to be pooled and this materially reduced the total installed capacity required. Before grid operation started the surplus of installed capacity over maximum demand was approximately 70 per cent. Immediately before the war this had been reduced to 15 per cent. Even if it could be assumed that under independent operation the figure might have been reduced to 40 per cent. the saving of 25 per cent. of present load is equivalent to an installed capacity of 3¼ million kilowatts or in modern parlance 3,250 MW. or 16 new generating stations of 200 MW., each costing probably £10 million—or £160 million in all. This had been done by an expenditure on the Grid of some £42 million so that the Grid has far more than paid for itself in this one respect alone.

Its second main function was to make possible substantial operating savings by the interconnection of the power stations so that the greater proportion of the units could be generated in the stations with the lowest running costs.

Theoretically the most economical plant should operate at 100 per cent. load factor and the least economical plant at almost zero. Practical operating conditions such as transmission limitations, inflexibility of the operating characteristics of existing plant, breakdowns and the human operating errors, make it impossible to achieve such optimum use of the plant.

Fig. 1, for which I am indebted to Mr. A. R. Cooper, shows the extent to which these practical difficulties cause departure from the ideal. It also indicates the scope for future economies. The total fuel costs of generation in Great Britain in 1949 were £75 million. Due to the Grid this cost is at least £10 million less

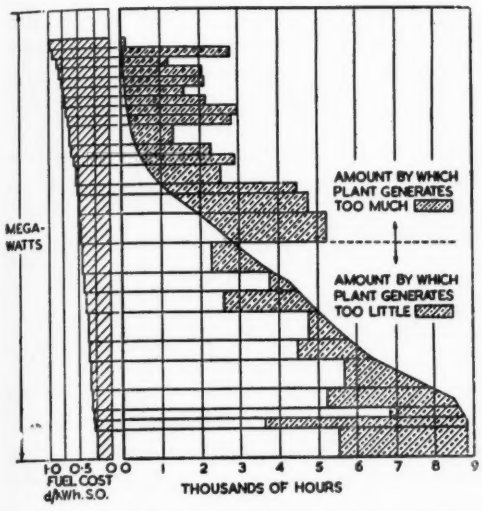
AMOUNT BY WHICH PLANT GENERATES TOO MUCH
AMOUNT BY WHICH PLANT GENERATES TOO LITTLE
MEGA-WATTS
1·0 0·5 0·0
FUEL COST d/kWh. S.O.
0 1 2 3 4 5 6 7 8 9
THOUSANDS OF HOURS

Fig. 1.—Load duration curve showing allocation of plant outputs.

than it would otherwise have been but Fig. 1 shows that there is probably a further improvement possible of some 10 per cent.

Such savings in themselves more than justify the cost of the Grid. However, I think the Grid has got beyond the stage when any attempt to justify it is needed, in fact to-day we can scarcely visualise electricity supply without it. During World War II it proved an untold blessing and the vast expansion of armament factories throughout the country was planned with the knowledge that their power supply was assured. Naturally the Grid had its troublesome times during the war but on the whole it came through with flying colours.

Even prior to the war the Central Electricity Board had established a large degree of national planning for generation. Although the Board did not own the power stations it was responsible for the capital charges on them and naturally in the course of years this resulted in the Board exercising considerable control over the siting of new power stations and their technical design. It was, however, becoming obvious that the position was rather artificial and that the power stations as well as the Grid should be nationally owned.

Prior to the war attempts had been made to carry into the distribution field the rationalisation which had been achieved in generation but the success of the Weir Committee was not repeated and no means were found of reconciling the distribution systems, voltages and tariffs of the 600 separate undertakings or of achieving the absorption of the smaller inefficient undertakings by the larger ones and building up logical areas of supply. The failure of the industry to rationalise itself led inevitably, under post-war conditions, to the nationalisation of the whole industry, both generation and distribution, on the broadest basis through the 1947 Act.

As most of you know the new organisation, which is now in its third year, is in two parts. The first consists of the British Electricity Authority who themselves own, extend and operate the original Grid plus all the generating stations. The other consists of 14 Area Boards who undertake the whole of the distribution in their areas and are in direct contact with the public. The Area Boards are supplied in bulk by the Central Authority—and have a considerable degree of autonomy. Their finance is, however, provided by the Central Authority who exercise a general over-riding and co-ordinating influence on their policies and technical development. The Central Authority deals with generation and transmission through 14 divisions whose areas are conterminous with those of the Area Boards.

Although the establishment of the Grid and the subsequent national ownership of the power stations have made possible a much freer choice of suitable sites for generating stations, the siting of these still remains a very complex problem. However, its very complexity emphasises the importance of separating out in our minds the various factors and considering their implications. It is well worth while doing so because the construction of generating stations involves the expenditure of vast sums of money and has become an important part of the nation's industrial effort.

The post-war programme of generating station expansion is an impressive one, comprising as it does 38 completely new stations. As with any other manufacturing works the siting of these must have regard to proximity to the source of the

main raw material—in this country coal—and proximity to the market for the manufactured product—electricity. There is, however, an even more important requirement. Water must be available in sufficient quantity for the condensers—preferably for direct cooling but in any event to provide the make-up for cooling towers—and this cannot be piped or pumped over long distances so easily as coal can be transported or electricity transmitted. Other important requirements are provision for the disposal of the waste products of the process, namely, the ashes and flue gases and, of course, the possibility of acquiring suitable land at a reasonable price and of such a character that the civil engineering works involved are not too expensive. Over and above these technical and economic requirements there are to-day many planning and amenity considerations—national defence—the present and future position of aerodromes—the future working of minerals—interference with historical buildings or beautiful scenery and the general repercussions on the life and industry of the country as a whole, all involving negotiations with different authorities. It will be seen that the perfect site must be almost non-existent and it is very desirable that the difficulty of meeting all requirements should be appreciated by the general public who are rather liable to be roused to righteous indignation without full knowledge of the facts and difficulties. I therefore make no excuse for referring to the question of power station siting in a little more detail.

Before considering the various factors it may be helpful to consider the general scheme of a modern power station and I have taken the largest of the four post-war programme stations which have so far been commissioned—Cliff Quay Station at Ipswich. On the whole this would be considered an excellent site though like all estuary sites it had to be piled under all the buildings. It is situated on the Orwell estuary and colliers of 4,500 tons will annually bring 650,000 tons of coal by sea to a jetty where the unloading cranes put the coal on travelling belts. These either stock it in the coal store formed by land reclaimed from the river or take it to the boiler house up the inclined belts. The ashes are sluiced into 40 acres of foreshore which have been enclosed and which will be gradually reclaimed. The main building consists of the turbine room with six 45 MW. machines nearest to the river and a boiler house with three 325 ft. chimneys. Further inland are the switching stations and four 132 kV. circuits.

In the boiler house there are nine 365,000 lb./hr. boilers with coal bunkers, pulverising mills and fuel pipes. As in all the larger modern stations the coal is first pulverised into a fine dust and then blown into the furnaces. There are forced draught fans on the roof and electrostatic precipitators for removing the exceedingly fine dust which is the chief difficulty arising from pulverised coal firing.

Turning now to a more general consideration of our problem of power station siting we will consider first the supply of water. It must be realised that a 300 MW. station requires approximately 15 million gallons per hour to be circulated through the condensers, more than the supply to a large city. This can either be done by providing a continuous supply of fresh cool water or by re-cooling it by cooling towers. Direct cooling is cheaper and more efficient but such quantities can only be provided on the larger rivers and estuaries or on the sea coast. Sites on the coast generally involve very high civil engineering costs and although estuary sites are usually much better in this respect there is no doubt that river sites are usually most attractive. There are, however, only a few rivers whose flow is sufficient for appreciable direct cooling purposes without resource to cooling towers, the most important being the Thames, Severn, Trent and Clyde. The Trent is of particular importance because as well as being of sufficient size and length to accommodate a number of large stations it flows through the Midlands and East Midlands coalfields and close to many heavy load centres. These coalfields are likely to be more intensively developed than any other. In the post-war programme 1,425 MW. of plant including five new stations have been sited along this river.

For other inland stations cooling towers are essential but even the make-up for a

300 MW. station requires approximately 150,000 gallons per hour and it is becoming increasingly difficult to find such quantities of water from the smaller rivers. This has led to the increasing use of sewage effluent for make-up purposes as has been done at the new Meaford Station near Stoke. Birmingham was a pioneer in the use of sewage effluent for this purpose and it would seem a natural development since the amount of sewage and the electric power requirements of an area tend to be roughly proportional. Some 1,540 MW. or about 13 per cent. of the plant capacity in the post-war programme will be using sewage effluent, normally without any form of treatment other than chlorination.

The coal supply problem is less difficult than the water problem but by no means simple. There is a popular idea that stations should be concentrated on coalfields. This would undoubtedly be the case if in the first place suitable sites and water supplies were available there and if in the second place the costs of transmitting electricity in bulk were less than the cost of transporting coal to stations nearer to the load.

Unfortunately water is seldom available at the coalfield in sufficient quantity and sites are expensive because of the cost of sterilising large columns of coal to carry the heavy machinery. In a few cases where conditions are favourable cooling tower stations on the coalfields are being developed. In general, however, the coal must be transported to the water. The question does arise, however, of whether such water supply should be sought near to the load or as near as possible to the coalfield. This brings in the relative cost of transport of coal versus electrical transmission (Fig. 2).

Transport by sea is undoubtedly far cheaper than transmission. Consequently estuary sites are particularly adapted to cheap generation as the coal can be delivered by coastal steamers and there is ample water for direct cooling.

The most important load centre in the country is, of course, London, accounting for about one-fifth of the total—hence the importance of the Thames Estuary for power generation. The post-war generating expansion programme includes 1,840 MW. of plant on the Thames but the available estuary sites within reasonable distance of London are not unlimited and it is quite foreseeable that in the not very distant future other means will have to be found for augmenting the London supply.

When it comes to transport by rail the case for transmission of the high load factor part of the load is often very much stronger. A comparison at 70 per cent. load factor made under 1949 conditions for various mileages and voltages shows that bulk transmission is economic compared with rail transport for distances over 20 miles and that 275 kV. is cheaper than 132 kV. transmission where the distance exceeds 90 miles.

In the days of many separate undertakings it was customary, and perhaps natural, for generation to take place as close to the load as possible. The Central Electricity Board had, however, already begun to change this policy and to consider generation problems on a broader basis. As I mentioned when referring to the Cliff Quay Station—which was, of course, planned by the Board—its capacity

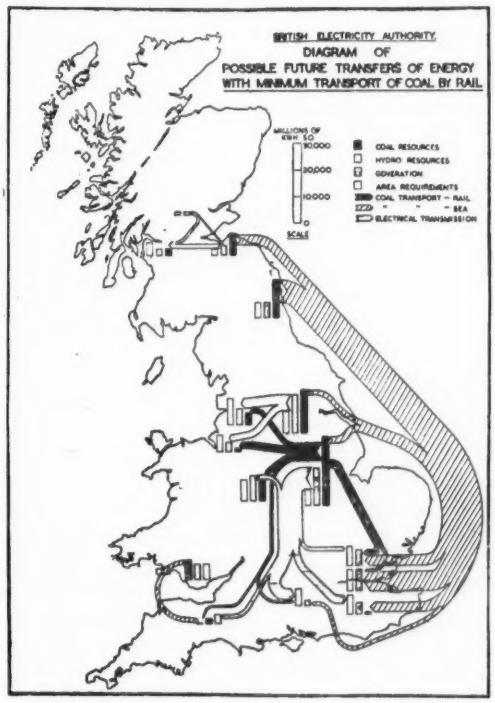

Fig. 2.

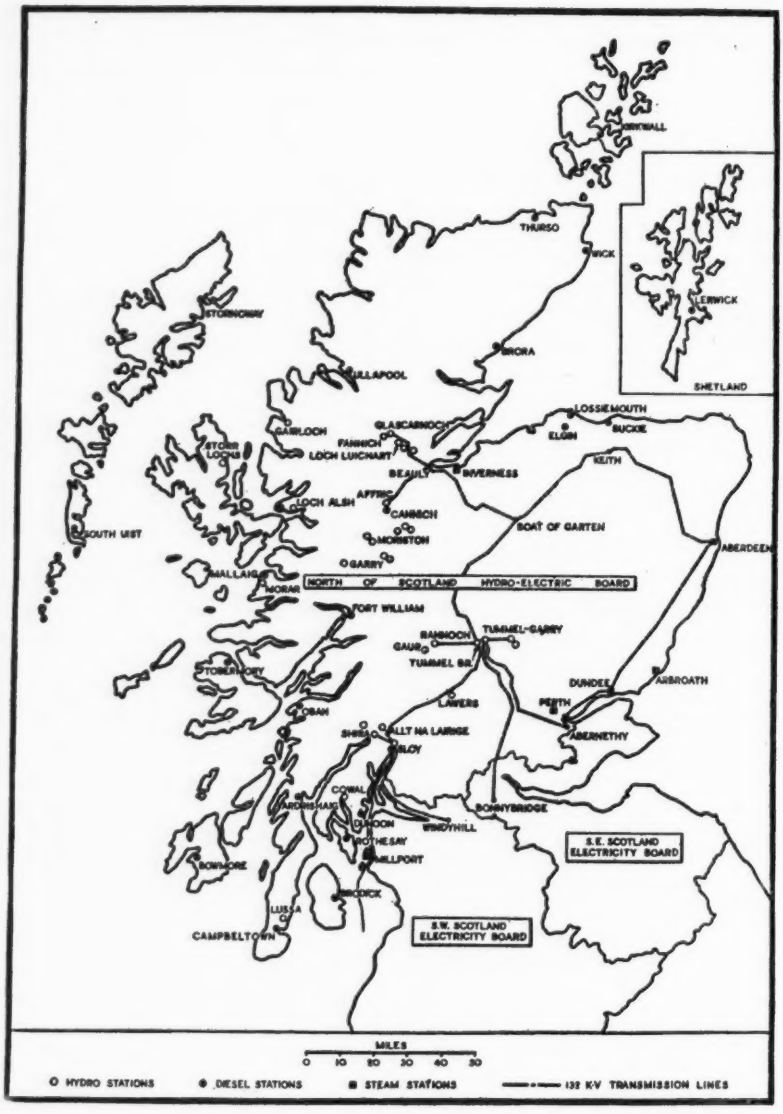

Fig. 3.

was far in excess of the local requirements of Ipswich and most of its output was transmitted by four 132 kV. lines to the areas north of London.

I hope I have given some idea of the national character and complexity of the very difficult problem of power station siting—a problem largely economic but with interesting technical features and having a fairly direct impact on the public.

Closely tied up with this power station planning is the ' Super Grid ' which the B.E.A. recently announced in the popular press. When the Grid was planned in 1926 132 kV. was adopted although this was looked upon by many at that time as rather bold compared with 110 kV. which had been widely used abroad. However, in 1926 the maximum load of the country was 2,700 MW. and the units generated were 7,000 million. By 1939 these figures had increased to 8,200 and 27,000 respectively and last year reached 11,000 and 49,000. It is therefore not surprising that thoughts began to turn on superimposing a higher voltage. The idea

of a Super Grid at double the present voltage was tentatively being considered when the last war broke out and British manufacturers had done considerable development work on the plant which it would require.

The war naturally put any such long-term project into cold storage but after the war was over the Central Electricity Board revived it and planned an experimental transmission at 275 kV. average (300 kV. maximum) from Staythorpe—one of the post-war power stations planned on the Trent near Newark—to West Melton near Sheffield. Two experimental spans were also erected at their Leatherhead Research Station. These developments were briefly referred to in the last Annual Report of the Board—that for 1947.

Such a Super Grid was referred to in more detail in Mr. Haldane's Presidential Address to The Institution of Electrical Engineers in 1948 and subsequently he was asked to develop his proposals in a paper to the first British Electrical Power Convention at Torquay in June 1949.

Two separate functions of the Super Grid will be, first, to provide greater capacity of interconnection between areas so as to enable spare plant to be more efficiently pooled and, second, to provide greater facilities for bulk transmission so that more new stations can be economically sited near the coalfields.

Hitherto I have been dealing entirely with thermal stations but I cannot close without some brief reference to our water power resources in Scotland and Wales. Relative to our total needs they are small but in themselves are quite substantial. So far they have been comparatively little developed—only some 250 MW. supplying only 2 per cent. of the country's requirements.

Towards the end of the war steps were taken to facilitate the development of the principal resources which are in the Highlands of Scotland. The object was mainly to bring industry and revived prosperity to the Highlands but also to save coal and increase our overall economy of generation. For this purpose the North of Scotland Hydro-Electric Board was established and exercises similar functions to the B.E.A. over the area shown in Fig. 3, which also shows the sites where the principal water power resources are to be developed.

At the present time projects are in an advanced stage of construction which will produce over 400 MW. and over 800 million units. Other schemes have been promoted but not yet started and still other schemes are under survey which will bring the new Scottish water power developments to over 1,000 MW. and 3,000 million units. However, this is still not a tenth of the figures for the country as a whole. In this country water power must always be a minor source of our power requirements.

The economics of the siting of water power plants and their associated dams and reservoirs is very complicated and I have no time to discuss it this evening. Neither can I attempt to study the interworking of hydro and thermal plants which largely determine the load factors for which the hydro plants are developed. Suffice it to say that in this country in order to get the best overall economy it is usually desirable to run the hydro plants at low load factor, i.e., to use them to take the peaks. This involves the Hydro Board transmitting large blocks of peak load into the B.E.A. system.

At the Fourth World Power Conference, held in London from July 10 to 15 150 papers were given. There was also in July, 1950, the bi-annual International High Tension Conference in Paris with a similar number of papers. As I have tried to cover the fields of these two Conferences in one lecture I feel that I have ample excuse for my inevitable shortcomings and omissions. I do hope, however, that to some limited extent I have given a useful picture of this problem of ' Power—its production and distribution ' which plays a larger part in our lives than the ordinary man perhaps realises.

GASEOUS FUELS AND THEIR SIGNIFICANCE IN THE FUTURE

by

PROF. F. H. GARNER, O.B.E.

THE gas with which we are most familiar is coal gas and it is appropriate that gaseous fuels should be included in the lectures at Birmingham of the British Association since the first public display of gas lighting in this country was made in Birmingham in 1802, nearly 150 years ago. An onlooker wrote ' The illumination of Soho Works (of Boulton and Watt) on this occasion was one of extraordinary splendour. The whole front of that extensive range of buildings was ornamented with a great variety of devices that admirably displayed many of the varied forms of which the gas-light was susceptible . . . and Birmingham poured forth its numerous population to gaze at, and to admire, this wonderful display of the combined effect of science and art.' (W. Matthews, *Historical Sketch of the Origin, Progress and Present State of Gas Lighting*, 1827.) Coal gas had been made on a small scale by Clayton some time in the late seventeenth century but industrial use had to wait a further 100 years. In the period which immediately followed Murdock's display, gas was largely made by cracking whale and other animal and vegetable oil and for many years there was discussion of the relative merits of coal gas and oil gas before coal gas was finally adopted ; Faraday first discovered benzene in oil gas many years before it was isolated from coal gas and until comparatively recently the railways used a cracked oil gas compressed in cylinders for illumination of railway carriages.

The engineering developments at the Soho Works made Birmingham the outstanding centre of engineering at that time, as shown by the fact that Watt and Murdoch came from Scotland to Birmingham for this difficult stage of development of their inventions, and there was a corresponding interest in Birmingham in technical education. As early as 1794 popular lectures were given on ' Mechanics and other branches of Natural Philosophy to a number of artisans,' the group of students (including workers at a foundry) who were described as ' the cast-iron philosophers.' A small society was formed to study natural philosophy and a variety of apparatus was made for experiments to illustrate the principles of mechanics, hydrostatics, electricity, pneumatics and astronomy. It is usually stated that Dr. Birkbeck's lectures to mechanics in Glasgow were the first in the United Kingdom but Matthews points out that Mr. James Luckcock gave similar lectures to the artisans of Birmingham many years before Dr. Birkbeck.

It may seem out of place in a paper on gaseous fuels and their significance in the future to discuss historical aspects but as we shall see later, the question of coal gas and oil gas in combination is a most important one as regards the future development of the gas industry.

The principal gaseous fuels other than coal gas are producer gas, water gas, blast furnace gas and natural gas. Coal gas, in the form of coke-oven gas and town gas, is obtained by the carbonisation of coal in one of the most efficient manufacturing processes of the present day in which gas, coke and liquid products such as benzole and tar, can be produced at a thermal efficiency of 80 per cent. and over. Coke-oven gas has the same general composition and characteristics as town gas, the difference being that town gas is made at a town gas works with coke as a by-product, usually nowadays in vertical retorts, whereas coke oven gas is a by-product from the manufacture of metallurgical coke, and finds many industrial uses.

Producer gas is manufactured by blowing a mixture of steam and air through an

incandescent bed of coal or coke and has a calorific value of about 150 Btu/cu. ft. as compared with the usual 450–500 Btu/cu. ft. for coal gas. Producer gas, taking into account its convenience in use, cleanliness and other factors, is one of the cheapest and most suitable fuel gases where large quantities of heat energy at high temperature levels are required as in furnace heating, in such applications as steel melting, metal heating and glass manufacture and in the carbonisation of coal. On the other hand, it is replaced by coal gas in other applications such as in the non-ferrous industry where the units of production are relatively small and there is a wide variety of different metal alloys to be handled in the same plant.

Water gas is produced by blowing steam through incandescent solid fuels such as coke or anthracite ; the fuel is first raised to incandescence by blowing the ignited fuel with air (' the blow ') and then steam is passed through the glowing mass (' the run ') until the temperature falls too low when the blow and run is repeated. The gases from the airblowing are used to raise steam in waste heat boilers and are not mixed with the water gas. The calorific value of blue-water gas is about twice that of producer gas, 290/300 Btu/cu. ft. and it is used to supplement town gas, but for this purpose its calorific value must be raised by mixing it with gas made by cracking gas oil and other petroleum fuels in a second chamber. Blue-water gas is also used as a raw material for the Fischer-Tropsch and allied processes for the manufacture of synthetic motor fuels and chemicals such as methanol and also as a source of hydrogen.

Blast furnace gas is obtained as a by-product in the smelting of iron ore with coke and is of low calorific value, 90–105 Btu/cu. ft. and is mainly used in the iron and steel industry itself for such uses as preheating the blast of air, heating coke ovens and as fuel for gas engines. It is also used in heating steel and, mixed with coke-oven gas, for open hearth steel manufacture.

So far all these gases are from coal. They all consist mainly of fuel gases, hydrogen and carbon monoxide, with diluents carbon dioxide and nitrogen.

Further important gases are natural gas and cracked gases from petroleum which are of minor importance in the United Kingdom but of great importance in the United States and of increasing importance in certain European countries such as France, Italy and Roumania.

At Heathfield in Sussex, a railway station was illuminated by natural gas for many years and two small gas fields in Yorkshire and Scotland were found in the recent explorations for oil. Natural gas is of very high calorific value, usually 1,000–1,200 Btu/cu. ft., and is pumped along pipelines for thousands of miles for use, as for example to Pittsburgh and other large towns in the United States. Natural gas consists principally of methane, but there is often present motor fuel which is removed by stripping with solvents, by compression or by adsorption processes. From natural gas, and from similar gases from petroleum, propane and butane fractions are separated and compressed into cylinders. Butane is mainly used for domestic heating and cooking where town gas is not obtainable. Propane is used in welding and similar applications, as is also acetylene, made from calcium carbide.

Methane is also obtained from sewage gas which contains about 70 per cent. methane, the remainder being carbon dioxide.

Methane is of such high calorific value that even in mixtures with large quantities of air, it can be used as a source of energy. There are very large quantities in the gases of coal mines and it is present in the up-cast ventilation of one-third of the coal pits in this country to the extent of 0·25–0·5 per cent.

Sir Alfred Egerton and co-workers at Imperial College have investigated very thoroughly the storage of liquid methane and its potentialities as a motor fuel for which it possesses many attractions owing to its very high anti-knock value, its H.U.C.R. being 14·5 as compared with 11·1 for iso-octane itself. It can therefore be used in an engine with high compression ratio at correspondingly high efficiencies.

Other petroleum gases are cracked gases from petroleum which contains the olefines ethylene, propylene and butylene,

in addition to the corresponding paraffin hydrocarbons.

Finally we must not neglect oxygen which, while not a gaseous fuel, is an essential component of all fuel mixtures. In the form of air we usually underestimate its importance as fuel but in the form of oxygen, because it has to be manufactured, it is of great importance in some of the latest developments for producing fuels of high economic value, as for example the complete gasification of coal. The production of oxygen at low cost is thus an integral part of many of these schemes.

Special Advantages of Gaseous Fuels

Coal is by far the cheapest available source of heat but it is being continuously displaced by more convenient forms of fuel such as gas, although it still retains the premier place in large power installations such as steam generating stations. Gaseous fuels are almost ideal fuels in that the quality of gas burnt can be easily controlled, the gases can be easily transported to the point where they are required, they can be burnt to give a wide range of temperatures as required for domestic and industrial uses, they lend themselves readily to automatic control so that the temperatures required, for example, in cooking or in melting glass can be readily maintained. Furthermore, combustion gives rise to carbon dioxide and water and there is no pollution of the atmosphere such as seems inevitable when coal is burnt on a small scale in the domestic grate, giving soot and smoke which by its pollution of the atmosphere and damage to buildings represents an enormous cost to the population both in health and in loss of efficiency.

Solid fuels like coal or coke are more difficult to transport and to feed to the combustion zone of furnaces although suitable apparatus is used for very large stations such as power houses and producer gas plants : it is difficult to control efficiently the rate of combustion and to provide the correct amount of air for complete combustion so as to get high thermal efficiencies. Compare the difficulty in feeding a solid in large sizes in a continuous even-flowing stream with the ease of flow of a fluid, either gaseous or liquid, and this flow can be controlled with a tap either by hand or by an automatic control to give the required temperature. By converting coal into a powder—pulverised feed—it is given some of the characteristics of a fluid in that its rate of flow can be controlled automatically ; for competition with true fluids, however, careful attention must be paid to a number of points such as fineness of pulverisation and absence of excessive moisture. Gaseous fuels have an advantage over liquid fuels in that the mixing process with air to prepare the fuel air mixture can be accurately controlled whereas the liquid fuels for mixing with air either vaporisation is necessary as in the petrol engine or, more usually, atomisation is employed in the diesel and gas turbine engines and in external combustion.

The chief factor in choice of fuel for any particular purpose is convenience in use. This depends on the types of mechanical devices which are available and the cost to the consumer.

Efficiency in Use

With such excellent properties, it would have been expected that still greater use of gaseous fuels would have been obtained but the important fact of thermal efficiency has to be considered. In the carbonisation of coal some 20 per cent. of the heat in coal is consumed in the production of gas and coke.

In the generation of electricity over 70 per cent. of the heat in the fuel is used up and dissipated largely in expensive concrete water cooling towers instead of being usefully employed as in such applications as district heating. Electricity, however, is readily converted to mechanical power and is in some cases the only form of energy suitable and such conversion can be done with 90 per cent. and greater efficiencies.

With gas, the next step is the production of heat and power with an overall efficiency of only 30–40 per cent. but still higher than that for electricity, namely 20 per cent., although it has to be remembered that much of the coal for the generation of electricity used is of high ash content and would be of little use as such for other purposes.

The various ways in which man uses

the energy of fuels can be classified under three different headings: first—space heating and cooking, that is providing warmth, cooking, hot water in homes, factories and other buildings. This consumes the surprising total of half of the coal in this country, that is 2 tons per person each year. It is in this field of space heating and cooking that is found one of the main fields for gaseous fuels.

The second heading is industrial heating and power: under industrial heating we have the whole range of industry, comprising brick and pottery manufacture, iron and steel manufacture, glass manufacture, cement, food and chemical manufacture, the paper and the textile industries, and under power the manufacture of various types of machinery parts such as the motor-car, of tools and of equipment; in this field gas and coke supply a large part of the industrial heating and electricity the main power requirements. This probably consumes in this country about 25 per cent. of the coal, that is 1 ton per person each year.

Finally we come to the third heading——transport, and this includes the whole of the transport of goods to be manufactured to the factories and workshops, from thence to the consumer, and transport by rail, road, sea and air. In this field liquid fuels are mainly used; although the locomotive still retains its hold on rail transport it appears likely that it will be displaced in this country, as it is being displaced in the United States, by the far more efficient diesel electric train.

Now, coming back to the question of space heating and cooking for which half our coal is used, it is interesting to consider to what efficiency this fuel is used and it is surprisingly low, only 20 per cent. as compared with 60 per cent. in the United States and 50 per cent. in the continent of Europe. This is largely due to the inefficiency with which coal is burnt domestically and this is the chief cause of the smoke and soot nuisance.

In the United States with a much colder climate, a higher temperature is maintained in houses than in the United Kingdom. The inefficiency of our domestic heating was remarked some 200 years ago by a visitor from Sweden, Peter Kalm. He arrived in London on February 8, 1748, and after less than a week he notes that 'the room in which people lived had a fire in it the whole day from morning to night, although most of the heat went away through the chimney.' The temperature of the room never rose above 46° F. although he had noted in Norway that a large room in which he lived was warmed to 66–68° F. by a little iron stove fired only twice a day and that when it fell to 60° F. they thought it cold and chilly.

Industrial Heating and Power

Convenience in use is one of the main reasons why gaseous fuels are employed over such a wide range of industrial uses from metallurgy to chemical factories.

By the carbonisation process, up to 25 per cent. by weight of coal is converted into gas, up to 65 per cent. into coke and 5–8 per cent. coal tar and benzol, and the gas industry is often described as a two-fuel industry—gas and coke. Both of these fuels have an advantage over coal in that they are smokeless fuels, and coke has its main field in the metallurgical industries. For other purposes coke has the disadvantages of solid fuels, namely more difficulties in transport and storage and greater labour costs in use.

One field in which coal gas is largely replacing solid fuels is the ceramic industry. The older type of batch kiln is being displaced by a tunnel kiln in which the clay ware enters at one end, is gradually heated up to firing temperature and then cooled down at exit end. With the gas-fired tunnel kiln, one therm of gas is equivalent to four therms of coal using the older batch process; this is accompanied by reduced labour costs, reduced smoke emission, better control of the firing process and hence production of better ware and also much better working conditions for the personnel employed.

Transport

In the field of transport, liquid fuels have a great advantage in that they share with gas the ease of transport to the point where they are used but if required to be mobile, i.e. movable with the engine as petrol in the motor car, the gas must be compressed into cylinders with added weight.

Much attention was given by the Birmingham Gas Department some years ago to the use of gas in road transport, but the heavy weight of the cylinders and difficulty of filling has limited this use of gaseous fuels.

In the future there is a possibility of some of the lower paraffin hydrocarbons being used as motor fuel. Propane, a gas boiling at — 42° C, is already being used in the United States as a motor fuel for buses for city work ; the gas is compressed in cylinders and a specially designed engine with 10 : 1 compression ratio is used and in addition to high thermal efficiency the exhaust is odourless. It is being used in a number of cities such as Los Angeles, Galveston, Wichita and Fort Wayne. Similarly, as already mentioned, some effort has been devoted to making liquid methane available for this purpose but in this case the methane is contained in vacuum insulated vessels of the thermos-flask type. However, engines of high compression ratio, to take full advantage of the high anti-knock value of methane, have not yet been made generally available.

Peak Load

In one respect, gaseous fuels and in particular electricity suffer a disadvantage as compared with coal and liquid fuels. Inevitably more fuel has to be consumed in the winter and it is not possible to store gas for winter use so readily as coal or liquid fuels, and not possible to store electricity at all.

In order to meet the demand in cold weather, carburetted water gas plants are largely used and these are rapidly brought into operation and are very flexible in output. It does, however, mean that some plant is idle in the summer time (although this is the season for repair and overhaul) and if the plant is not used to full capacity then expensive capital equipment is lying idle.

In addition to the increased demand throughout the winter season there are each year a few days or longer of intensely cold weather which call for unusual supplies of gas and here again the carburetted water gas plant is useful. Any methods to store gas for use at a period when there is a very large demand are of interest, even though all of them may not be practicable in the United Kingdom. In the United States some attempt has been made to even out the supply by storage of natural gas in depleted gas and petroleum reservoirs underground and by storage in liquid form. At first sight the idea of pumping gas into the ground with the certainty of recovering it substantially in full seems somewhat fantastic but it is estimated that the volume of underground storage capacity now in use in the U.S.A. amounts to 400 million million cu. ft.

In liquid form, some fuel gases such as methane can be stored at low temperatures by the use of well-insulated tanks, the low temperature being maintained by withdrawing some of the liquid in the tank and using its latent heat by evaporation as in the domestic refrigerator.

In the United States, to meet the peak demand for a few days, pipe batteries consisting of interconnected tanks made of commercial gas line pipe of 24–36 in. diameter and from 200 to 400 ft. length are used for the storage of gas under pressure.

One disadvantage of coal is the cost of transport, particularly to large cities and this applies to coal used in gas works which are normally in or in the neighbourhood of large cities. The proportion of the chemical energy in the coal which is used in such transport may amount to as much as 10 per cent. and more. In addition the physical handling and storage of the large quantities of coal for gas and electricity work is often a problem of major importance. If gas could be made at high pressure, it might be possible to carry out the gasification at the pithead and transmit the gas by high-pressure pipeline to the city, using less of the fuel energy in transport than with a solid fuel. It is claimed that four tons of coal converted to gas and coke for domestic heating does the same work as was formerly done by five to six tons of coal, but that if pressure gasification were adopted this figure could be reduced to three tons. Storage under pressure would then be a feasible way of meeting peak demands.

The petroleum refineries, particularly those engaged in cracking operations, produce large quantities of gas which is available for town gas supply or rather

for raising the calorific value of low grade gas since it has a very high calorific value, much higher than the usual 450–500 Btu/cu. ft. Manchester is already drawing some of its gas from the Petrocarbon works. With such petroleum gases of high calorific value, processes have been devised whereby they are converted to larger volumes of gas of lower calorific value such as the normal town gas supply of 450–500 Btu/cu. ft. In one of these processes, the hydrocarbons and steam are passed through the fuel bed of a water-gas generator ; in an alternative process which has been installed in several cities in the U.S.A. the hydrocarbons mixed with steam and air are passed through externally heated tubes containing a suitable catalyst.

Meeting Increased Demand for Gas

The demand for gas is increasing so that considerable thought has been given to methods of increasing the yield of gas at the expense of coke. One method which has been used for many years is the production of water gas from the coke which is then carburetted with cracked gas produced from gas oil so as to obtain a gas of equivalent calorific value to coal gas. As already mentioned, the chief use of carburetted water gas in the gas industry up to the present has been to provide for peak loads and this amounted to 18 per cent. of the town gas distributed in 1947. Gas oil has been principally used for carburetting in the United Kingdom. There is, however, an increasing demand for this type of fuel for other purposes, notably for the highly efficient diesel engine with the result that in the United States 70 per cent. of the oil used as water gas enricher is fuel oil, and a similar development is taking place in France. A previous objection to this use of petroleum products, namely that they were imported, will largely disappear in view of the great expansion taking place in petroleum refining in this country.

In Germany, complete gasification of brown coal, which is devoid of caking properties, has been accomplished by the Lurgi pressure process with the help of oxygen obtained by Linde-Frankl air-liquefaction process ; and this and other processes involving hydrogenation of coal to give methane have been actively studied by the Gas Research Board with the view to complete gasification of coal. These processes have the great advantage that a wide range of coals can be used whereas carbonisation is restricted to coals of a high caking power and a low ash content. The demand for caking coals for the manufacture of industrial coke is very high and the quantity available is limited.

Underground Gasification

Amongst other forms of gaseous fuel which may be used in the future are those derived from underground gasification. The suggestion that coal may be gasified in the mine is attributed by the Russians to Mendeléeff in 1888 but the putting into practice of such a scheme appears to be due to a statement by Sir William Ramsay at a dinner of the Institution of Mining Engineers in 1912. He stated that ' there was no question that gas and not coal was the fuel for the future. If they could succeed in getting up gas from the bowels of the earth to utilise in explosive engines instead of coal, the country's supply of energy would last a great deal longer than was likely at present.'

A shaft was sunk in this country and some work was done in the U.S.A. but the war, 1914–18, stopped the work. Air would be introduced into the seams of coal at one point and gas taken off at another point. The Russians started work in 1931 but have concealed most of their information behind the iron curtain. Within the last few years, work has been done in the United States, in Belgium, in France, and more recently in this country under the auspices of the Ministry of Fuel and Power at Newman Spinney near Sheffield. The difficulties of obtaining usable gas have proved tremendous and so far no results have been obtained which would indicate that methods are yet available for successful underground gasification. The highest calorific value of gas produced is usually below 100 Btu/cu. ft. The prospects, however, of eliminating nearly all the labour and hazards associated with mining make the problem one of the most fascinating at the present time.

The use of gas of such low calorific power is quite practicable in gas turbines

and one of the most important problems of the future of gaseous fuels is that associated with the gas turbine.

Gas Turbines

Although the most directly usable type of mechanical energy is rotary motion, as in the bicycle or motor-car wheel, the ship and aeroplane propeller or the lathe, the earliest form of motion developed by Savery, Newcomen and Watt was the reciprocating form which had to be converted into rotary motion. It was the genius of Sir Charles Parsons who made Heron's very early idea of a turbine possible. This use of reciprocating motion is interesting since the two main types of power used until steam became available, the windmill and water mill, did employ rotary motion.

Similarly, in the conversion of chemical energy from combustion reactions into power, reciprocating motion was first developed as in the spark ignition engine and diesel engine and was converted into rotary motion in the wheel of the motor-car or the propeller of the aeroplane. Then much later Sir Frank Whittle developed the gas turbine for aircraft, using kerosene as fuel.

The possibilities of the gas turbine in the field of power generation on a large scale are now realised and for this purpose cheaper fuels must be used than the distillate fuels such as kerosene ; these are coal and residual fuel oils and gases derived from them.

The gas turbine has advantages over the steam turbine in that the size of plant should be much less with consequently lower capital costs. It also presents possibilities of economy in the quantity of cooling water required. Gases are in some ways more suitable than steam for a series of heat cycles, but high efficiencies depend on the use of high temperature cycles and the possibility of using such high temperatures depends on the production of materials which retain strength and resistance to oxidation at high temperature. The efficiency of the gas turbine at present is lower than that of the steam turbine but comparable thermal efficiencies of 28–32 per cent. are expected with plant under consideration such as compound plant with regenerator.

Coal may be used directly in the gas turbine as a fuel in pulverised form or used to form producer gas which is then burnt : a further scheme is to use the heat from the combustion of coal to heat air or other vapours and gases which are circulated through the gas turbine. One of the most promising schemes is the combustion of coal under pressure and the use of the hot flue gases in the turbine. There are many formidable problems to be considered, in particular the effects of the solid particles in the combustion gases and the effect of the combustion gases themselves on the turbine blading and on heat exchangers if used. These difficulties might be avoided by *gasification of the coal and burning the gas* in the gas turbine.

There are other possible uses for the gas turbine which are being investigated in utilising the large quantities of low grade heat available from a number of industries. The flue gases from industrial furnaces, as for example, from glass or cement manufacture are at high temperatures after they have been usefully employed in making these products and the hot gases can be used in gas turbines. Similarly the exhaust gases from gas turbines might find use industrially for drying or for supplying precombustion air to furnaces.

Conclusion

Thus in considering the future of gaseous fuels, since gas is the most convenient form of fuel for many purposes, a problem of great importance is to make gas available in larger quantities for industrial and domestic use at reasonable cost by such processes as complete gasification.

The next problem is that of underground gasification with its unpromising results so far, but such tremendous possibilities, if ever successful, in the elimination of part or the whole of the dangerous and difficult mining operation.

Finally, the application of Whittle's gas turbine to larger scale power production is perhaps one of the most important technical problems of the present day. It appears to have a clear field in the medium power units such as for rail and sea transport but it remains to be seen how far it can compete with the steam turbine in the largest power units.

BIRMINGHAM AND THE INDUSTRIAL REVOLUTION

by

W. K. V. GALE

THE world of to-day is a world of mechanical power. Instances of the ways in which mechanical power affect our daily lives are unnecessary—it is sufficient to say that without this power, civilisation as we know it would be impossible. We have become dependent upon machinery of many kinds, and this, in its turn, can only function as a result of man's ability to harness various forms of natural energy.

It took man a long time to develop means of controlling natural energy, and so using it for his own purposes. 2,000 years and more ago, steam was recognised as a potential source of energy, but the story of man's success in his efforts to turn it to useful work extends only over the last 250 years. During that period of great endeavour and achievement, Birmingham and its neighbourhood played a very important part. It is with this aspect of the Industrial Revolution—the development of steam power, and the contributions made by the Midlands, that I propose to deal.

The first recorded efforts to use the natural force of steam took place in about A.D. 50 when one Hero of Alexandria described a method of producing rotative motion. Whether or not he actually made a machine is not known, but the principle, though inefficient, was mechanically sound—so much so that in the last century instances could be found of small engines actually at work, which were constructed on Hero's principle.

After Hero's time the problem of producing a practicable mechanism for harnessing steam power remained, and it was tackled in various ways—none of which was successful as far as we know. In the meantime, other possible sources of power were explored, and wind and water were adapted for various purposes.

By the end of the seventeenth century, wind and water power were used on a considerable scale, in spite of their unsuitability for many purposes. Wind power, for example, utilised by means of the windmill, was unsuitable for iron smelting, which is a continuous process, and water power could only be used where there were suitable streams or rivers. These are not over abundant, in this country at least, and are not always in a convenient position relative to centres of consumption, or of raw materials for a particular product.

They were, however, all that could be had at the time, if we except the very limited power which could be obtained from the limbs of man and beast. It is obvious that with such restricted sources of power, the development of industry on a large scale was impossible. The position was difficult, for several causes were already operating to set industrial developments in motion. Certain machines were already in existence, which only needed a reliable and adaptable source of mechanical power to render them of great value.

But the industry which needed power most urgently at the end of the seventeenth century was that of mining. It was quite possible, for instance, even if it was slow and uneconomic, to produce metal ores entirely by hand power, but as the miners followed the minerals deeper, and so developed true mining as distinct from quarrying or opencast working, so the surface waters followed the miners, and the problems of drainage became, in many cases, unsurmountable. Such was the state of affairs when, in 1698, Thos. Savery produced his elementary form of steam engine. It was wholly unlike anything which we should recognise as a steam engine to-day, though, here again, the principle, like that of Hero, found its uses many years later. The Pulsometer steam pump is, in its essentials, only a form of Savery engine, though its detailed construction is vastly improved.

Savery's engine was very limited in

application and does not merit description in detail. It is only necessary to say that it used steam at atmospheric pressure to produce a vacuum in a closed vessel into which water was then forced by the pressure of the atmosphere. A fresh charge of steam in the vessel ejected the water, through a suitably arranged pipe, and the steam was then condensed by cold water, so starting the cycle of operations again.

The engine would only lift water a very short distance, and that is all it would do. Its use was practically limited to mine drainage ; the only other thing it could be used for was to lift water which had been used over a waterwheel, back to the mill pond for re-use. Savery's engine had a certain amount of success, but its inefficiency, coupled with the fact that the mechanical skill required to make it was rarely to be found at the time, limited its application.

It was not until Thos. Newcomen came on the scene a few years later, that there were any marked developments in the application of steam power. Newcomen was a Devonian by birth, but his most important work was done in the Midlands. For this reason, coupled with the fact that his engine was of great historical importance, he is worthy of a little more attention.

The first Newcomen engine was erected in the year 1712, at a coal mine between Dudley and Wolverhampton. The ground has been so altered by subsequent mining operations, that so far it has been impossible to locate the historic place. The engine had much in common with that of Savery, though it incorporated many new features, and was entirely different in appearance. It consisted of an open-topped cylinder, fixed directly over a boiler, and having a piston which was connected by a chain to a heavy wooden rocking beam, pivoted on the stone wall of the engine house. At the other end of the beam, chains and rods passed down the shaft of the mine to the underground pumps. The beam was weighted so that it normally came to rest with the piston at the top of the cylinder. When steam was admitted to the cylinder, it helped the piston to move to the top, and so allowed the pump rods to fall, and the pumps to fill with water. A jet of water was then injected into the cylinder, which condensed the steam, and so formed a vacuum under the piston. As the top of the cylinder was open, the atmospheric pressure acting on the piston forced it down, so raising the other end of the rocking beam, and the water in the pumps. A simple arrangement of levers and catches connected to the beam made the engine self-acting and so long as it was supplied with steam, it would keep on working.

The engine was large and cumbersome, but it was simple, and most of the parts could be made on the site by the local blacksmith and carpenter. Only the cylinder and piston caused difficulty in manufacture, and these, for many years, were made by the Coalbrookdale Company in Shropshire. The Newcomen engine had certain advantages over the earlier Savery. It was self acting, which the Savery was not, and, since the pumps and engine were separated the former could be placed underground where they were needed, and the latter at the surface, which was obviously more convenient in view of its great size.

It had one great fault—its inefficiency gave it a prodigious appetite for coal. This was, at the time, unimportant in such districts as South Staffordshire, where coal was plentiful and very cheap, but elsewhere it was a serious problem. So serious was it, in fact, that at the Cornish tin and copper mines, where all the coal had to be carried from Wales in coastal sailing vessels and on the backs of pack animals, the usefulness of a Newcomen engine as a means of drainage was far outweighed by the running-costs. The Newcomen engine would certainly pump water better than anything hitherto invented, but the problem was how to make it do so economically.

A Scotsman, James Watt, found the answer. He was born in 1736, when the Newcomen engine was already some years old, and as a boy showed great curiosity about anything mechanical. He was given what mechanical training was possible at the time, and when still a young man, he set up a shop at Glasgow, where he undertook the manufacture of all sorts of tools and instruments. To this shop was brought a model of a Newcomen

engine for repair. It was used in Glasgow College for demonstration purposes, and Watt's instructions were simply to make good certain breakages, and restore the engine to a workable condition. This he did, and then, to the great benefit of the world, he went much further than he was commissioned to do. On working the model, he was impressed by its inefficiency, and he set himself the task of finding out why so little work was done for so large a consumption of fuel, and of remedying the fault when he found it.

Watt had his living to earn, and his spare time was limited. Nevertheless, he studied the Newcomen engine both practically and theoretically, and at last, in 1765, two years after he had repaired the model, he found the answer. The result was his invention of the separate condenser, a great step forward in the history of mechanical power. I shall deal more fully with his invention a little later ; in the meantime it is necessary to relate what was done about making engines on the new principle, and to see how Birmingham began to come in to the picture.

Watt had no money to develop his invention. He entered into partnership with a fellow Scot for this purpose, but before anything had been done other than the building of an experimental engine, Watt's partner went bankrupt, and the partnership terminated. At this juncture Watt entered into partnership with the Birmingham manufacturer Matthew Boulton, whom he had met previously. This was the beginning of one of the most important partnerships the world has yet seen, for there was, at the time, no one who was in a better position to help Watt than Boulton.

To see why this was so it will be necessary to go back a little. Matthew Boulton was born in 1728, and so was Watt's senior by a few years. He was a Birmingham man, born at his father's house near to where Snow Hill Station now stands. Boulton has been described as ' Birmingham's greatest citizen,' and while I cannot presume to judge, I feel that sometimes he has not always received the credit he deserves. Some of his biographers are inclined to stress his business abilities and to draw the obvious conclusion that Boulton as the business man and Watt as the scientific investigator, wholly unfitted for the commercial world, made ideal partners. This is certainly true, but it hardly does justice to another side of Boulton's character. Even a cursory glance at the Boulton and Watt collection of documents in the Birmingham Reference Library should suffice to show that Boulton was also no mean engineer.

His parents were not wealthy, and his beginnings were small. As a youth he took an active part in his father's business of buckle making, and here he soon found that he had little scope for his abilities. The large factory as we know it to-day was then very much a thing of the future. It is true that a few factories existed, but there were not for metal working. Boulton's father carried on his business in a little workshop attached to his dwelling house, working at the bench himself, with the aid of perhaps one or two journeymen. In this he was only following the practice of the day—the ' garret-master ' was then the only type of employer in Birmingham.

Matthew Boulton, however, was a man of great vision. He developed his father's business until the premises were far too small, and then conceived the idea of building a factory, in which large numbers of specialist workers would be employed, and where many branches of metal working would be carried on simultaneously. Here was another novelty. At that time each manufacturer specialised in only one branch of a trade ; often he made but one type of article, or even a single size of one type. To bring all the processes under one roof and to have control of the raw materials as well, was Boulton's idea. He wasted no time in putting his ideas into practice.

In 1761 he acquired the lease of a site at Soho, at that time just outside Birmingham, and began to erect buildings and machinery. New plant was added from time to time and by 1765 Boulton had the best equipped and largest metal working factory in the world. By the time Watt's engine had been developed, Boulton was thoroughly established as a successful manufacturer. But he had one major problem—that of power. His machinery was driven by a waterwheel worked by the little Hockley brook, which was likely to freeze up in the winter, and become

short of water in the summer. Boulton's power problem made him all the more interested in Watt's invention, and he was shrewd enough to foresee a market for it as well. Indeed, at the time, he was one of the few who could see any merit at all in Watt's new engine.

In 1775 Watt obtained a 25-year extension of his original patent for the separate condenser, and in the same year he entered into partnership with Boulton to develop the new engine. The partnership was to last for the duration of the patent, that is 25 years. The first step was to get Watt's experimental engine from Scotland and set it to work at Soho, pumping tail-race water back into the mill pond for re-use. A standard form of engine was quickly evolved and only a year after the partnership had been formed the new firm concluded the erection of its first two engines.

It is now time to say something about the features which made the Watt engine so superior to its immediate predecessor, the Newcomen. Illustrations of the two reveal very little difference in appearance, and Watt's engine could still only effect reciprocating motion. What, then, was the difference? It was simple but effective. Watt in the study of the Newcomen model had concluded that since the cylinder was first heated by hot steam, then cooled by cold water, again heated and so on, that there must be a tremendous loss of heat at every stroke, which could only be made up by burning more coal. In this he was absolutely right, and here was the explanation of the enormous coal consumption of the Newcomen engine compared with the work it did—in short the reason for its inefficiency.

Watt devised a separate condenser, kept the cylinder permanently hot by means of a hollow casing filled with live steam from the boiler, and obtained a permanent cooling effect on the condenser by immersing it in a cistern of cold water. By this means the heat losses were reduced greatly. A little attention to detail improved matters further, and before long a Watt engine was doing as much work as a Newcomen with only a quarter of the fuel. It is interesting to note that Watt's conclusions were reached by theoretical means (as he has himself recorded) and verified by practical experiment, actions fully in accord with recognised practice to-day.

The first two engines built by the partners were installed locally. One went to Bloomfield, Tipton, for pumping water from a colliery, the other to Willey, near Broseley, Shropshire, where it was used to blow a blast furnace. Here was another new departure. The growing iron trade had need for steam power, and this was only the first of many engines supplied for iron working.

The blast furnace engine was to the order of John Wilkinson, the celebrated eighteenth century ironmaster, who had also invented an improved boring machine. The business connection was to the mutual advantage of Wilkinson and the Soho partners. One of the great problems of the day was to bore a large cylinder accurately, and Wilkinson's boring mill went a great way towards providing a solution. The cylinders for both the first two engines were made by Wilkinson (in the case of his own engine he made everything else as well, to Watt's design) and for many years he continued to supply all the Boulton and Watt cylinders, Soho being responsible for the design, and the more difficult parts, such as the valves and valve gear.

The first two Watt engines have long since disappeared, but in 1777 an engine was built which still exists. Erected at Smethwick for pumping water for the Birmingham Canal Company, it worked on its original site until 1895. Three years later it was removed to the Canal workships at Ocker Hill, Tipton, for preservation, and there it remains, the oldest existing steam engine in the world.

Before the partnership had been in being long, a third famous name was added to the Soho group—that of William Murdock. Born in Scotland in 1754, Murdock had made his way to Soho on foot in search of work, and was engaged as the firm's engine erector and agent in the field. He remained a trusted and worthy employee for many years, until he retired in fact, in 1830. The engagement of Murdock was of great importance to the firm, for the fact that they now had an able lieutenant gave Boulton time to concentrate on commercial matters, and enabled

Watt to devote his energies to research and development. The immediate problems of pumping and furnace blowing having been settled, the pressing need was for an engine which would turn rotating machinery directly, without the use of a water-wheel, and so could be used where there was no water power.

Watt was not the only one to recognise the fact that rotative motion was urgently needed. Boulton pressed him to produce a rotative engine, ' the people are steam-mill mad,' he wrote on one occasion, and even while Watt was at work, in 1780, a Newcomen engine was equipped with a crank, which enabled it to turn the stones of a flour mill. The engineer, Wasborough, of Bristol, and the mill owner Pickard, of Birmingham, obtained a patent for the use of the crank, and thus forestalled any move which Watt may have proposed to make in this direction. He might perhaps have been accused of being slow, for the crank was well known long before his time, but his slowness was justified, for when his rotative engine did come out, in 1782, it was a great advance over the Newcomen adaptation. He overcame the crank patent with his ingenious sun and planet motion, which was used successfully for many years.

Watt's engine of 1782 was double acting, that is steam was applied to both sides of the piston, instead of to one side only as in all previous engines, and it was also worked expansively, which introduced further economies in working. The rocking beam was retained, but at the cylinder end, where formerly the connection between the beam and the piston rod had been made by a chain, an alternative was necessary, because there was now a upward push on the piston as well as a downward pull. Watt at first used a known method, a rack on the piston rod working into a toothed sector on the end of the beam. It worked, and it produced the desired effect, but it was a crude and clumsy device, and wholly unsatisfactory to a man of Watt's turn of mind.

In the place of the rack and sector Watt introduced, in 1784, his celebrated parallel motion. It was a simple and effective arrangement of links, which, while permitting the end of the beam to move in an arc, restricted the movement of the piston rod within the necessary vertical line. I have been asked why Watt did not use the crosshead and slide, which became the common device some years later. He may have thought of it ; I do not know, but if he had it is very doubtful if he could have obtained machinery to make it at the time. On the other hand the parallel motion gear could be produced without difficulty on the machines of the day.

The state of perfection to which the steam engine had been brought by Watt, and the fact that it was now available for such a multitude of duties, meant that the Soho partnership had more than enough to do. By 1794 the sons of the original partners, Matthew Robinson Boulton and James Watt junior, were taking an active part in the business, and in the same year James Watt himself began to withdraw from his business concerns and to concentrate on experimental work. Boulton was still busily engaged with the Soho Manufactory where he had started a new department, to make coins and medals. He was quick to see the value of steam power for coining, and was a pioneer in the minting of high quality coinage. For some years he supplied great quantities of coins to the Royal Mint, and also equipped that undertaking and many others, with coining machinery of his own design. Thus he gave to Birmingham another trade which it retains to-day.

The engine business became more and more the concern of the younger partners, and in 1795 there occurred a crisis which was to be a severe test for their abilities. You will recollect that I said earlier that only the valves and valve gear were made at Soho ; the cylinders were produced by John Wilkinson. In 1795, owing to a disagreement between Wilkinson and his brother, the Wilkinson works became the subject of litigation and the supply of cylinders were threatened. How could this problem be met ? The young partners might have approached the Coalbrookdale Company in Shropshire, who could cast the cylinders, but their boring machinery was at that time hardly up to the standard required. We know from existing correspondence that several possibilities were considered, but in the end the Soho firm took the obvious course—they

decided to build their own foundry and boring mill.

Once the decision was taken, no time was lost. A site was acquired on the bank of the canal about a mile away from the original Soho Manufactory, and work on the buildings and plant commenced. In three months, working almost entirely to their own plans—for the project was novel and they had little hope of using the experience of others—the two junior partners had the first part of the new foundry at work. In a short while the new works, Soho Foundry, had achieved great fame, and it was to become the training ground for generations of engineers who were to bring honour and prosperity to the Midlands.

Of course, all the while the use of steam power was spreading, other industries grew with it. More engines meant a demand for more iron, and at the same time made it possible to produce more iron ; steam engines enabled vast increases in production to be made in a host of trades and so caused increased demand throughout industry. Each trade had become complementary to the others—the Industrial Revolution was already in full swing.

And now I must turn to a new development. The engines of Boulton and Watt could supply most of the stationary power needs of the time, but the great increase in industrial output had brought about a need for improved transport. So far no one had turned the powers of steam successfully to either land or water transport.

It is true that as early as 1784 Murdock had made a working model locomotive (which still exists) but it had not proceeded beyond the model stage. The Soho firm was early in the field with marine engines and played a great part in the development of mechanical water transport, but in the sphere of land transport the first important developments were due to Richard Trevithick, a Cornishman. Much of Trevithick's work was done in his native county. But some of his machines were made in the Midlands, and while I am dealing mainly with Birmingham and district, all Trevithick's work was of such importance in steam engine history that I must give it more than mere mention.

Trevithick did much to improve the efficiency of steam engines generally, and as mentioned earlier he did pioneer work in land transport, but it is in one direction particularly that the developments for which he was responsible are most important. Prior to his time steam had not been used at more than a pound or two above atmospheric pressure. Newcomen's and Watt's engines both relied on the pressure of the atmosphere to do the major part of the work, and of course required some means of condensation and a supply of cold water for their operation.

Steam at a pressure of about 40 lb. per sq. in. was proposed by Trevithick, and in spite of ridicule and assurances that he would blow himself up, he succeeded in making a workable engine. The first thing it enabled him to do was to make his engine portable, for the expansion of the steam down to about atmospheric pressure without condensation did away with the condenser and cold water supply. It also became possible to make small engines which could be placed anywhere on the simplest of foundations. The monopoly of the great heavy condensing engine was broken, and Trevithick's high-pressure engine found many applications.

But I do not want to suggest that condensation as a principle in steam engine manufacture was finished. Indeed, engines of the Boulton and Watt type, and simple modifications of them were made for fifty years and more after Trevithick's invention ; for some purposes they remained without equal. The principle of condensing was applied to high-pressure engines too, and it is very widely used to-day in the most efficient steam plants in the world.

To return to Trevithick, his first locomotive engine was made in Cornwall in 1801, and it is interesting to note that it ran on road wheels, not on rails. It was followed in 1803 by a locomotive made to run on a rail track—this time in South Wales. There were many difficulties to be overcome before the locomotive engine was a success, not the least of which was the fact that the rail tracks of the time were not strong enough. But Trevithick's locomotive engine proved the practicability of steam power for land transport and paved the way for Stephenson and others who gave the world its railways.

One final word about Trevithick. I have said that engines prior to his time used steam at very low pressures. Their boilers were suitable for a few, but not for 40 or 50 lb. per sq. in. Trevithick had to design boilers specially, and his work can be seen to-day, almost unaltered, in the single flue shell type boiler known as the ' Cornish.'

By about 1820 the steam engine, improved by various inventors, had become so firmly established that it might have seemed impossible for it to be superseded. Indeed, until about 1880 it remained the supreme provider of power for all purposes. About 1880 however, the gas engine began to come into prominence, and many were made by the Smethwick firm of Tangye. The engine was popular, but relatively short lived, for it soon had to face the competition of electricity. Gas engines could be used in any corner of a factory where power was required, had no stand-by charges and were simple. But electricity had all these advantages and more, and the gas engine soon began to be displaced by the electric motor.

Electricity, however, is not a prime mover ; the generators must be driven. Gas engines were used to some extent for this purpose, and as the older steam engines were too slow and unsteady in running for electric generation, new types of high-speed, close-governed steam engine were developed. Very fine examples of this type of engine were made by the Midlands firms of Willans of Rugby and Bellis & Morcom of Birmingham. They were high pressure, compound, and condensing, thus combining all the features of the earlier engines, and they held the field for some years.

In 1884, there appeared the revolutionary steam turbine of C. A. Parsons. This was a high-speed machine, very efficient in operation and extremely smooth running—the ideal prime mover for electric generation. It is scarcely necessary to add that by far the greatest proportion of electricity used in this country to-day is generated by means of the steam turbine.

I have brought the story, as far as I have been able, to the present day, except for a mention of the internal combustion engine using petrol or oil as a fuel, and the gas turbine ; these will be dealt with in other papers. Limitations of time have meant that some topics have been dealt with more briefly than I would have liked, and others have been omitted altogether. I should, for example, have liked to have said something about the local engineering and metal working trades, which were closely connected with many of the developments of which I have spoken. But I hope that I have said enough to show that Birmingham and the Midlands have a historical record of which they need not be ashamed.

THE UNIT OF HEAT

by

DR. EZER GRIFFITHS, O.B.E., F.R.S.

THE Royal Society has issued a leaflet entitled ' The Unit of Heat.' It states that the Council of the Royal Society recommends that in the Society's publications quantities of heat, and all other dependent concepts such as latent heat, heat of combustion, entropy, etc., should in future be expressed both in joules and in calories. This recommendation is to implement the decisions of international bodies which had given the subject consideration. The International Unions of Physics and of Chemistry have recommended that the fundamental unit of heat should be the joule (10^7 ergs) and this has been accepted by the Ninth General Conference of Weights and Measures, 1948.

These decisions mark the culmination of efforts at reform which have been going on for more than half a century. It is of

interest to glance back at the history of this topic for the British Association was a pioneering force in its introduction. A committee which had been set up by Section A to report on experiments for improving the construction of practical standards for electrical measurements, published as an appendix to its report for 1896 extracts from replies received dealing with the question of the unit of heat.

A letter of inquiry had been sent out in 1895 by a member of that committee, Mr. E. H. Griffiths, later Principal of the University College, Cardiff, and for many years Treasurer of the Association. The letter asked for opinions on the nature and magnitude of the thermal unit recommended for adoption, and it was sent to the leading European and American physicists. Among the names of those who replied are some which are familiar to the student of science: Dieterici, Paschen, Planck, Chappius, le Chatelier, Callendar and Rowland, to mention a few. The consensus of opinion was strongly in favour of an absolute unit and the majority agreed upon the joule.

In the last twenty years some workers have made it a practice to express their results in joules and giving in addition the equivalent values in calories precisely defined. Thermochemical data is a case in point where a thermochemical calorie had been adopted which has the value 4·1840 in absolute joules. Another calorie which has been defined in terms of the electrical units is the International Steam Table Calorie. It is the quantity of heat equivalent to $\frac{1}{860}$ international watt hour. One mean international joule is now accepted as being equal to 1·00019 absolute joules, so the Steam Table Calorie in absolute joules becomes 4·1868.

In passing it might be mentioned that Callendar in 1915 took the calorie as 4·1868 joules.

As regards the various calories defined in terms of the heat capacity of water we have the 15° calorie which according to an assessment of the latest determinations is 4·1855 and this is the value given by the International Committee of Weights and Measures. In addition there are the Mean 0° to 100° and the Maximum Density of water calories.

In the table below are given the values in absolute joules of the various calories. The values are given to a greater number of significant figures than is required for most work except that of the very highest accuracy.

Description of calorie	Value in absolute joules
International Steam Table Calorie; I.T. Cal.	4·1868
15° Calorie; Cal_{15}	4·1855
4° Calorie; Cal_4	4·2048
Thermochemical Calorie or Defined Calorie	4·1840
Mean 0° to 100° Calorie	4·1897

In new work the author can use joules alone or both joules and calories but he should not use calories without defining the calorie in terms of joules.

The position as regards the British thermal unit is equally unsatisfactory. It would seem that the British thermal unit has no very definite origin or legal definition. Of the four different British thermal units to be found in the literature two are commonly met with. They are the 60·5° F. unit (1054·54 joules) and the Steam Table unit (1055·06 joules).

In conclusion it should be pointed out that the international system of electrical units in use until 1948 has now been superseded by the absolute system of electrical units, so in future when calorimetric apparatus is standardised by the dissipation of a measured quantity of electrical energy the calibration factor is obtained in absolute joules.

THE WORK OF CHARLES LAPWORTH

It was fitting that the Geology Section should devote one of its sessions at the Birmingham Meeting of the Association to an appreciation of the work of Charles Lapworth, who spent the greater part of his working life in Birmingham as the first Professor of Geology in Mason College and later in the University of Birmingham which he did so much to promote and establish. The symposium consisted of four papers and the substance of these appears below.

Introduction

by

Prof. W. S. Boulton

In opening the symposium, I can only refer, in the few minutes at my disposal, to the general sequence of Lapworth's work, stressing more particularly his researches in Shropshire and the related discoveries in the Midlands, leaving to the speakers who follow me to deal in more detail with his work on the Midland Coalfields, on Graptolites and in Scotland.

My association with Lapworth began in the year 1883, two years after his appointment in the recently established Mason College. He had just returned from his exciting and exhausting work in the North-West Highlands of Scotland at the end of a strenuous session of teaching at the College, and had already published the first instalment of his 'Secret of the Highlands' in the *Geological Magazine* of that year. The strain of this work following upon a prolonged period of intense, concentrated labour while living in Scotland, to which I will refer in a moment, brought on a severe mental and physical illness, from which he never entirely recovered. In the years that followed he was always liable, after a bout of hard work, in which he never spared himself, to get a return of some of the symptoms of that early breakdown.

From 1864 to 1881, when he came to Birmingham, he had been a schoolmaster, first in Galashiels and then in St. Andrews, and in his spare time and vacations he began his geological rambles among the Lower Palaeozoic rocks of the Southern Uplands, soon to discover fossils in rocks hitherto thought barren. In company with his friend James Wilson, a detailed study of the geology around Galashiels in 1869 led to his first publication in the *Geological Magazine* in 1870. And then followed, year by year, more than twenty publications in the *Geological Magazine*, the *Quarterly Journal of the Geological Society* and the Journals of the Edinburgh and Glasgow Societies, some of them in collaboration with his friends John Hopkinson and Alleyne Nicholson. Many of these dealt with the then obscure and little known graptolites with which his name is inseparably associated; and all this time he was a voracious reader of the literature of the Lower Palaeozoic rocks in Britain and abroad.

These years in Scotland were perhaps the happiest, as they were the most strenuous, years of Lapworth's working life. He was then, as he used to say, laughingly, an amateur, unrestrained by authority, unorthodox in many of his ideas and conclusions.

In after years he seemed rather hesitant in the publication of much of his work in detail; his reputation was such that his opinion was perhaps too readily accepted by the younger geologists, and perhaps his intellectual integrity prompted him to see, beyond the work already done, a field as yet unexplored, which might supplement or modify his conclusions. Certain it is that much of his detailed work never saw the light of publication. But with his students and close friends he was always willing and even eager to reveal and discuss his views and conclusions.

As he slowly recovered from his breakdown, he began in 1885 his field work in

Shropshire, and continued these researches, on and off, for some fifteen years.

The *Ordovician* of Shropshire occurs in the Corndon-Shelve District west of the Longmynd, where practically the whole of the Arenig, Llandeilo and Bala Series is represented from the Stiper Stones Quartzite at the base, resting on the Cambrian Shineton Shales, up to the Chirbury Series at the summit, and with two notable series of volcanic ashes and tuffs—the Stapeley Ashes in the Arenig and the Hagley Ashes in the Bala. In the Caradoc District east of the Longmynd, the Bala Series only is present. These beds were mapped in the greatest detail on 6-inch or 25-inch maps, where available, and sometimes on large maps of his own construction. Graptolites, Trilobites and Brachiopods were diligently collected and used for zoning purposes. Nowhere else had the whole Ordovician sequence been mapped in such detail.

The underlying *Cambrian* was also mapped, including the Shineton Shales under the Stiper Stones, the Comley Area east of Caer Caradoc, and along the east flank of the Wrekin. He proved the Shineton Shales to be Upper Cambrian, and presumed the underlying sandstone equivalent to the Hollybush Sandstone of the Malverns, while the Quartzite below the Hollybush Sandstone, containing basal fragments of the Uriconian rhyolite, he classed as pre-Cambrian together with the Uriconian. Trilobite fragments found by Callaway in a limestone band at the base of the Hollybush Sandstone at Comley were recognised by Lapworth to belong to the Lower Cambrian genus *Olenellus*, and this he reconstructed and named *Olenellus Callavei*. He subsequently found the Olenellus Limestone at the Wrekin, and the discovery of *Paradoxides Groomi* above the Olenellus Limestone, both at Comley and the Wrekin, proved that Lower, Middle and Upper Cambrian are present in Shropshire. These discoveries not only proved for the first time that a Lower Cambrian fauna is present in England, and also the pre-Cambrian age of the Uriconian, but also virtually settled the pre-Cambrian age of the Longmynd, whose sediments, some 27,000 feet in thickness, could have no place in the Shropshire Cambrian.

The Longmynd, and the neighbouring Haughmond Hill and Bayston Hill, were mapped on the 6-inch and 25-inch scales, and two great divisions recognised : the Eastern half, or Stretton Series of grey and green shales and flags, and a Western half, or Wentnor Series, consisting of coarse grits and conglomerates, mostly red in colour, and related by Lapworth to the Torridon Sandstone of Scotland. Blake's supposed unconformity between the two divisions was not confirmed. The conglomerates, with pebbles of igneous material of Uriconian type, in the Wentnor Series, dipping eastward from Pontesford Hill, and suggesting the pre-Longmydian age of the Uriconian, as well as the possibility of major faulting and inversion of large portions of the Longmynds were questions which were raised tentatively, but without positive conclusions.

The *Uriconian* rhyolites, andesites and tuffs, with their intrusive basic rocks in the Wrekin, Wrockwardine, Lilleshall, Caer Caradoc, Lawley and Pontesford, were mapped in outline. Lapworth never had the advantage of an early systematic training in microscopic petrology, but he had an uncanny eye for spotting slight shades of colour and texture, and would sometimes give his own fancy names to specimens of igneous rock for identification in the field.

Lapworth's researches in Shropshire were never published as a whole and in detail. At the International Geological Congress in 1888 he exhibited a large map, and gave a brief account of his work up to that time, and outlines appeared from time to time, in Section C of the British Association in 1886, for the Geologists Association in 1894 and 1910, and scale sections of his Ordovician in the Survey Summary of Progress in 1915. Since then, however, most of his work has become generally known.

Soon after coming to Birmingham, his field work in the Midlands quickly led to new discoveries related to those in Shropshire.

In the Nuneaton-Atherstone area, the Stockingford Shales had been mapped as Upper Barren Coal Measures and the underlying Hartshill Quartzite as altered Millstone Grit. Lapworth's discovery of Cambrian fossils in the Shales rendered it

probable that the Quartzite is also Cambrian and comparable with the Wrekin Quartzite. Subsequently, a *Hyolithes Limestone* with horny brachiopods was found in the upper part of the Quartzite, followed by the discovery of *Olenellus* just above it. Illing's subsequent detailed work in the Shales showed that all three divisions of the Cambrian are represented in this area.

Below the Quartzite the Caldecote Volcanic Series of tuffs, quartz-felsite and intrusive basalt were related in age to the Uriconian of the Wrekin.

As far back as 1882 the Lickey Quartzite, south of Birmingham, which was originally mapped as altered Llandovery Sandstone, he linked with the Cambrian Quartzite of Nuneaton and the Wrekin, while below the Quartzite are the Barnt Green volcanic tuffs answering to the Caldecote Volcanic Series.

The mechanical deformation of rocks on the smallest to the grandest scale was often prominent in Lapworth's mind, and when called upon to give his Presidential Address to the Geological Section of the British Association in Edinburgh in 1892, he chose ' The Fold ' as his subject, and gave a graphic account of its life history from its inception, septal overturn, to final collapse. From this he passed to folds on a continental and oceanic scale, citing the great geo-anticline or arch of North America with its central sag, and its complementary geosyncline or trough of the Atlantic with its central volcanic ridge or buckle, and thence to the giant wrinkling of the great globe itself.

In later years, relieved of much of his teaching, he turned to his beloved graptolites, and in 1901 began work on his *Monograph of British Graptolites*, eleven parts of which appeared from 1901 to 1918. In this work he acted as Editor, and had the great good fortune to secure the devoted assistance of the late Ethel Wood (Dame Ethel Shakespear) and Dr. Gertrude Elles, happily with us to-day, who were responsible for the drawings, with the aid of a specially designed microscope, and the written matter.

While insisting on the fundamental importance of Geology as a pure science, he realised our obligation to use its facts and principles, wherever possible, in aid of industry. Applied Geology was a notable part of his teaching for students in Mining and Civil Engineering.

His advice was frequently sought in selecting suitable sites for impounded reservoirs, as in the Derwent Valley and the Rhayader District, and for supplies of underground water, especially in the Midland Red Rocks, for domestic and industrial use.

In this brief outline of Lapworth's work his indirect contribution to the advancement of our Science should be referred to. He was a brilliant and inspiring teacher, and much of the research work of his old students and intimate friends was the outcome of his suggestion and encouragement, and continued under his wise and sympathetic guidance. One recalls the coalfield researches of Walcott Gibson, one of the early pupils to enrol in his classes in Mason College ; the Permian and Old Red Sandstone work of Wickham King ; Cobbold's detailed researches on the fossils and zoning of the Shropshire Cambrian ; on graptolites and Lower Palaeozoic stratigraphy by Miss Ethel Wood and Dr. Gertrude Elles, and others too numerous to mention.

No geologist of our time has done more to advance and enrich our Science, both by his own brilliant researches, and through his generous aid to others, than Charles Lapworth.

Work of Charles Lapworth in the Southern Uplands

by

Dr. G. L. Elles

Charles Lapworth was a self-taught geologist, but he taught himself in the best possible school by work on the open hillside and its intersecting streams. Though he was entirely self-taught, Lapworth was undoubtedly richly endowed with the mental faculties which are needed for the successful geologist, and these he carefully trained and cultivated : a keen faculty for observation, a good eye for country ; a wonderful perception of minute lithological changes in both horizontal and vertical directions. He also seems to have had a veritable genius for spotting where fossils occurred, and a

skilled hand in their extraction, combined with inexhaustible patience in their collecting. Moreover, he possessed an exact and retentive memory which rarely played him false.

Time and again he set himself to take up and master anything he found necessary for his work. He soon found the need for large scale maps, larger than any available : he surveyed the ground and made the maps. He found graptolites were the only fossils in the Southern Uplands and having decided that they were, beyond question, traces of organisms, he studied them exhaustively and trained himself to become a first-rate palaeontologist.

Above all, he possessed the power to realise vividly the conditions that might have given rise to the observed phenomena, so that in imagination he saw them all at work and studied their results. This characteristic was responsible for the saying that when once Lapworth had made up his mind on a subject, it was no use to contradict him, *for he was there when the rocks were made.*

He was moreover a skilled draughtsman, and this was no small part of his equipment. His drawings of graptolites, drawn with a camera lucida through the microscope of his own devising, are wonderfully natural, and the sections and drawings with which he illustrated his Upland work are not only accurate but artistic and beautiful.

His driving force was derived probably from two main sources, (a) his overruling love of truth, and (b) his delight in overcoming difficulties. The mainspring of his research was to widen the bounds of knowledge, true and tested. For personal honour or admiration he cared little, nothing short of exhaustive knowledge satisfied him, and that is why his work requires so little revision. As he realised how much confidence was placed in his lightest word by those who knew and trusted him, he grew slower and increasingly cautious in his publications. He knew that much of his work must be regarded as preliminary and tentative.

The keynote of Lapworth's brilliant stratigraphical work was struck in the country round Galashiels where he was a schoolmaster from 1864 to 1875. For the first two years he was content merely to explore and collect graptolites, and it was not until 1866 that he started his serious systematic work and soon realised that his own observations led to very different ideas from those current in the literature of the geological world.

In the pre-Lapworth days, the rocks of the Southern Uplands were considered to be a normal ascending sequence of greywackes (14,000 to 26,000 feet in thickness) interrupted occasionally by thin seams of black shale with graptolites. These rocks were considered to dip steadily, though not very regularly, from south to north off a supposed anticline at Hawick and were considered to represent a single series. No difference in the graptolite faunas of the different shale bands had been detected and since *all black shales and mudstones* were then regarded as of Llandeilo age, graptolites therefore were useless as time indices.

Then came the epoch-making work of Lapworth and with his methods of work modern stratigraphical geology was founded. His studies were directed especially to the attainment of a knowledge of the vertical range and distribution of graptolites in the field, and he found that by utilising his knowledge he could unravel the complicated stratigraphy and structure of the whole region.

His first published work on the *Silurian Rocks of Galashiels* appeared in 1870, and in that he only *suggested* that there were *two* distinct rock groups characterised by different graptolite faunas ; the uppermost the Gala, which he then regarded as of Bala-Caradoc age, since it clearly overlay the Moffat Shale group ; and following the prevalent view of the time he did not dare consider this as other than of Llandeilo age.

But from that time onward Lapworth's ever fearless regard for the truth gradually overcame his veneration for officialdom, and as his researches extended further and further afield, he became convinced that the ' one clear conception ' of the earlier investigators rested upon a very serious misconception regarding the age of the rocks ; and in 1876 he was able to show conclusively that all black shales were *not* necessarily of Llandeilo age ; also he demonstrated clearly that within the 300–500 feet of black Moffat Shale there

were three perfectly distinct faunas of graptolites, and it was only the lowest that corresponded with the Llandeilo, the middle representing a portion at any rate of the Bala rocks of Wales, and the top representing Lower Llandovery of Wales and probably more : to the lower and middle of these the terms Glenkiln and Hartfell were subsequently given. The upper fauna, he also showed at this time, was capable of a further division into three, which he termed Birkhill, Gala and Riccarton. Subsequently he was able to show that the Birkhill and Gala, which he termed 'Valentian,' corresponded with the English - Welsh Llandovery - Mayhill and Tarannon. Such was the revolution effected by the obscure elementary schoolmaster of Galashiels. He used in a remarkable way fossil organisms which many geologists had not even regarded as fossils at all, and offered to the official Geological Survey the solution of a problem which had hitherto baffled them entirely.

His removal to the Madras College, St. Andrews, in 1875 gave him longer holidays and greater opportunities for completing some of his research. Thus, in 1878 after three years of intensive field work came the great Moffat paper which at the present day remains universally acknowledged the greatest and most original contribution to the life sequence and structural relations of that or any other British region. Having mapped the various outcrops for the ten years previously, he was able to interpret the highly folded nature of the rocks, basing his conclusions throughout on the vertical distribution of the graptolites as giving the true succession. In this paper for the first time *species* of graptolites are employed throughout in grouping and correlation of the stratigraphical subdivisions. A 'zone' is in his view essentially a stratigraphical bed or group of beds identified by palaeontological criteria. The highly convolute nature of the folds was admirably shown in the maps and sections attached to the paper.

Lapworth then decided to test his conclusions by application to the Girvan area where a different (shelly) facies is developed and the graptolite zones are intercolated with beds of trilobites and brachiopods and other shelly fossils ; his Moffat work was entirely confirmed though the thickness of rocks at Girvan is twenty times as great as at Moffat. We now know that in the Southern Uplands every degree of folding is manifest from the isoclinal fold to the smashed overfold, faults reveal themselves, order is apparent in the chaos and the complexities in the general structure made clear for the first time. Repetitions of the strata as indicated by the graptolite faunas show that we have to deal with *hundreds* of feet only, not thousands.

Thus, the Upland work demonstrated once and for all the value of graptolites as zonal indices. Well justified is his note of triumph : 'Zonal work is probably destined to effect in the history of geological research a revolution as great and an advance as rapid as those brought about by use of the microscope in biology.'

Lapworth's investigations on the graptolites themselves were certainly the outcome of his Upland field work, and in 1873 he published 'An Improved Classification of the Rhabdophora.'

Perhaps the most significant thing in it is the recognition of the function and character of the small dagger-like structure named the *Sicula* as the primitive germ of the whole rhabdosome, and its relation to the bud or buds of the primitive rhabdosome. In order to write this paper he had accumulated a vast amount of material not only in our own country but from the work and collections of others all over the world. Thus he was fully equipped for his invaluable treatise on the Geological Distribution of the Rhabdophora (1879–1880). In this for the first time not only are graptolite zones established over Britain but the distribution of the zones and their contents all over the world, was analysed, tabulated and described so far as was then possible, and the inference established of the reliability of graptolites as working stratigraphical indices.

Much later he contributed to Walther's *Lebensweise fossiler Meeresthiere* 'The Mode of Life of Graptolites' (1897). In this he pointed out that graptolites occur in greatest numbers in black carbonaceous shales, and good specimens are practically confined to rocks of that type. Graptolitic

remains however, did *not* provide the carbonaceous matter for they are found as foreign bodies in it.

The carbonaceous matter was due to organic life which like the graptolites was strange to the deposits, and it was probably vegetable in origin, e.g. Sargassum. Lapworth believed that graptolites lived attached to marine plants, which like Sargassum might break away periodically in their life history and be carried far and wide over the seas. The attachment was a *nema* or fine thread, first regarded as a solid rod or *virgula* but known later to have been a hollow organ whose growth kept pace with that of the organism.

Lapworth advanced the theory that while the earliest and dendroid graptolites stood upright in shallow water, the later and more typical forms (true graptolites) hung suspended from Sargassum-like seaweeds, so that they were drifted over sea-waters as pseudo-planktonic organisms by currents, and this fact determined the wide distribution of the graptolite zones.

With regard to the mode of occurrence of graptolites, two important facts are brought out :

(a) the time taken in distribution in space was negligible compared with the rate of deposition of the rocks in which they occur.
(b) quietness of the waters rather than depth determines their accumulation.

In 1875 a great change in Lapworth's life took place, For a short period he was an assistant master at Madras College, St. Andrews, where he wrote (1) the Moffat paper, (2) the paper on Scottish Monograptidae, and (3) the Distribution of the Rhabdophora.

Then came a still more significant change, when he was appointed to fill the newly established Chair of Mineralogy and Geology at the Mason College, Birmingham. Here a congenial atmosphere and greater opportunities of the post and the greater leisure allowed him to devote himself to geological work of all kinds. Birmingham became the veritable Mecca for the graptolithologists all over the world. So many demands were made upon him that he could give little time to his own work. Fortunately, Lapworth's numerous friends in the Midlands and others interested in geology came to the rescue and a fund was raised to provide him with an assistant professor to undertake much of his routine work and leave him some freedom for his research. Shortly after 1891 Professor Watts was appointed to this post and Lapworth could set the seal upon his work and start the *Monograph of British Graptolites* which had been planned for so long and for which he had at last devised a suitable method of reproducing the illustrations. In this he was most ably assisted by Dame Ethel Shakespear to whom he had imparted some of his own skill as a draughtsman. This work is inspired throughout by Lapworth and the part dealing with the Diplograptids is particularly his own.

Truly the man must be claimed as one of the foremost geologists of all time, whose epoch-making work in geology gave new life to everything he touched—stratigraphy, palaeontology, tectonics, and petrology. Such men never die, for their ideas and methods permeate their scientific work to encourage and inspire those that come after, and to blaze the trail. It is most fitting that our tribute should be given here in Birmingham where so much of his life was spent.

Charles Lapworth and the Coal Commission of 1905

by

Prof. W. G. Fearnsides, F.R.S.

Unlike Professor Boulton and Miss Elles who were privileged to work with Professor Lapworth in his laboratory and in the field through many years, my personal association with him was mostly through Professor Watts. I am none the less proud to acknowledge that it was as much his influence as that of Hughes and Marr and Watts which kept me working on the Cambrian and Lower Ordovician rocks and fossils among the North Wales mountains during my time at Cambridge. It was an inspiring influence. Following generations will venerate the memory of the author of the Ordovician System.

Coming now to the special topic on which I have agreed to speak—Lapworth's

work for the Royal Coal Commission which reported in 1905. With Mr. A. Sopwith, a distinguished mining engineer, he assembled the available quantitative information and was responsible for Part III of the Commission's Final Report, dealing with 'The Available Coal Resources of District 'B,' Staffordshire, Warwickshire, Leicestershire, Shropshire and a small portion of South Derbyshire' associated with Edward Hull, J. J. H. Teall and Aubrey Strahan. He was the only non-Survey member of the Geological Committee of the Commission, and himself wrote the Sub-report, 'On the Concealed and Unproved Coalfields of District B.' I say at once that, since I became Geological Adviser to the West Midlands Division, Lapworth's original interpretations have been the basis on which the N.C.B. has worked. His inferences have been extended, but in no case yet has Lapworth in essential matters been proved entirely wrong.

I do not know when Lapworth's coal mining work was started. Probably it was not long after his arrival in Birmingham, for throughout all his time there few of the more critical and experimental enterprises where the problem was complicated by faulting and unconformity did not have the advantage of his guidance. We have record in the *Birmingham Mail* of a lecture on 'Our Future Coalfields' in 1894 which caused a stir. He had authoritatively advertised that the Thick Coal resources of South Staffordshire could not last much longer. His appointment to the Coal Commission followed service in the Board of Education's Departmental Committee which considered the position and work of the Geological Survey, and in 1900 had reported 'The first and foremost duty of the geological surveyor is to map the country' not doubting that if this duty is conscientiously discharged economic results of high value will inevitably follow.

Having commented that in its boring for coalfield extensions the N.C.B. is following Lapworth's lead, it is proper also to say that Lapworth used the information of the pioneer geologists of the Geological Survey especially Jukes and Ramsay, as we are using that collected by their successors now. Lapworth had better evidence than the Commissioners of 1873, and he really knew that the several beds within the Coal Measures succession were deposited as continuous sheets across the district 'B' with newer beds in general overlapping the older towards the Midland Ridge and with the coals gathering closer together and measures thinning towards the south. His friends and pupils had by that time shown that coal-bearing grey measures pass up into red beds with index bands of Spirorbis limestone, with so little discordance that these too are properly accounted Upper Coal Measures—the Permian boundary is to be looked for higher up above the Keele Beds, and a gross unconformity recognised below the Bunter Pebble Beds. He did not discount the intermediate Permo-Triassic breaks; but saw the several divisions of the New Red Sandstone overlapping one beyond another from north-west to south-east, against or across the anticlinal structures of present exposed coalfield ridges.

Concerning large scale structures, Lapworth enlarged upon the dominance of the Staffordshire deep syncline pitching southwards within the termination of the Pennines. He saw this basin flanked by folded 'platforms' of old rocks divergent on the Shropshire and Leicester sides, and on these small coalfields preserved in dimples, those on the Shropshire side overlapped by Upper Coal Measures, those of Leicester more deeply denuded and blanketed with Trias. The main trough he regarded as an area of more or less continuous pre-Trias Sedimentation and divided by the uplift of the Cannock-South Staffordshire Coalfield into separated bays, the Wolverhampton and the Birmingham basins. He computed the coal content of these basins separately and concluded that each may contain more than 5,000 million tons of workable coal which is three times as much as was accounted as accessible under red measures and less than 4,000 feet deep in the gape of the North Staffordshire Coalfield. Of the floor of the Shropshire platform he remarked the north-east to south-west Caledonian lines complicated by the north-south structures of Malvernian; in Leicester what of older rocks are visible have like the coalfield dimples, a Charnian north-west to south-east trend. Lapworth

was a firm believer in recurrence of bending and displacement along established structural lines of strength and weakness, and it was at his behest that, although they could not adopt the whole of it, the Geological Committee included as Appendix III of their report the famous, startling and, as we now know, over-optimistic 'Sub-report of the concealed portion of the Coalfields of Yorkshire, Derbyshire and Nottinghamshire' by Prof. P. F. Kendall of Leeds. The beginning of the century, when these syntheses of evidence of concealed structure were produced, was a time of great prosperity for coal owners and of rapid developments for coal production in all the coalfields. More explorations and new sinkings were in progress than in any period since. The Doncaster area was being opened up beneath the Magnesian Limestone and following the stepping down of Sandwell Park and Hamstead across the eastern boundary fault of old South Staffordshire, Baggeridge was newly sunk beyond the western boundary fault. Cannock's new pits beneath the Trias were already doing well, and it is not surprising that even Lapworth was somewhat optimistic in his calculation of possible coal reserves. In estimating 'proved' reserves he was, with Sopwith, much more cautious ; and it can be fairly recorded that now in 1950 extensions of coal workings are just about reaching, but have at no point gone beyond, the boundaries of the probable Concealed Coalfield areas as delineated upon their map. There is just one area, between Rugeley and Pipe Ridware and Armitage, probed lately by N.C.B. and proved to hold coal seams at shallow depth which were not suspected.

Lapworth and the North-West Highlands Succession

by

Dr. Murray Macgregor

Following on his researches into the stratigraphy and structure of the Lower Palaeozoic rocks of the Southern Uplands, carried out between 1869 and 1879, Lapworth decided to undertake an examination of the Durness-Eireboll region in north-west Sutherland. Three considerations influenced his choice. In the first place this was the only Highland area in which Lower Palaeozoic rocks had been obtained in comparative abundance ; in the second place good coastal sections were available ; and in the third place the succession of rock-groups represented within the area was a matter of dispute.

When Lapworth commenced field work in the Durness-Eireboll district in the late summer of 1882 there were two main views held by geologists regarding the North-West Highlands succession. The first was associated mainly with the name of Murchison and had been elaborated by him in a series of papers published between 1856 and 1861 in the *Quarterly Journal of the Geological Society* or in the *Sectional Transactions* of various meetings of the British Association. His final views regarding the North-West Highlands succession may be stated in tabular form as follows :—

Younger or Eastern Gneiss .	Silurian
↑ Upper Limestone	
Upper Quartz-rock	
Limestone	
Serpulite Band .	Lower Silurian
Fucoid Beds	
Lower Quartz-rock	
(Unconformity)	
Red Sandstones and Conglomerates . . .	Cambrian
(Unconformity)	
Older or Western Gneiss .	Laurentian or Fundamental Gneiss

He regarded the succession from the Lower Quartz-rock upwards as 'demonstrably an ascending order' and had no doubt but that the quartz-rocks and limestones were followed in natural sequence by the Eastern schists and gneisses and constituted along with these one continuous series, the age of which was determined by the evidence of the fossils obtained in the limestones at Durness.

The second view regarding the succession was that of Nicol. His interpretation may be set out in tabular form thus :—

Lower Silurian	Limestone	
	Salterella Grit	
	Fucoid Beds	
	Quartzite with pipes	
	Massive Quartzite (basal grit)	
	(Unconformity)	
	Red Sandstones and conglomerates	
	(Unconformity)	
	Western Gneiss . .	Eastern Gneiss

He maintained, in opposition to Murchison, (1) that the limestone is the highest member of the Durness-Eireboll Series, (2) that the Upper Quartzite and Upper Limestone of Murchison and other observers were merely the lower quartzite and limestone repeated by folding; and (3) that the Eastern Schists and Gneisses did not overlie the quartzite-limestone series conformably but that 'the line of junction, where this conformable succession is said to occur, is clearly a line of fault, everywhere indicated by proofs of fracture, contortion of the strata and

West of Loch Eireboll

I Lower Quartzite
- Pipe Rock . . .
- Massive Quartzite (white)
- Thick-bedded to flaggy quartzite (pinkish)
- Thin basal pebbly layer

Unconformity

Hebridean Gneiss

powerful igneous action' (*Quart. Journ. Geol. Soc.*, XVII, 1861). In support of his view he adduced a number of acute observations. Thus, in his account of the sequence on the east side of Loch Eireboll (i.e. on the promontory of the An t-Sron and the slopes of Bealach Mhairi to the east) he clearly recognised that where the Pipe Rock appears to dip eastwards under the gneiss of the hill it was actually brought up from below the limestone by folding and was inverted, the openings of the worm-tubes and the ripple-marks on the *lower* faces of the rock showing, as he said, 'a complete reversal of the strata' (*Quart. Journ. Geol. Soc.*, XVII, 1861, p. 89). In the case of the famous Knockan Crag section he describes the junction between the 'fine-grained gneiss' at the top of the cliff and the quartzite-limestone beds below as 'a line of fault with powerful lateral compression.'

In his approach to the problem Lapworth used the same method of attack as he had employed with such signal success in the Southern Uplands. The first stage was the careful sub-division of the definitely sedimentary Silurian into lithological or palaeontological zones which could be easily recognised in the field and mapped out in detail. His succession for the Loch Eireboll Area shows :—

East of Loch Eireboll

IV Eireboll (or Durness) Limestone
- (c) Grey, white and mottled limestones arranged in several well-marked zones.
- (b) Dark flaggy limestones and calcareous shales.
- (a) Thin impure dolomitic limestone of a yellowish buff-colour.

III Salterella — Grit or Quartzite.

II Heilam or Fucoid Beds.
- Quartzose flags underlying dark-blue shales.
- Fucoid limestone : impure dolomitic shales.
- Fucoid Zone : flaggy grey shales.

. . . Highest Zone of Pipe Rock.

By using these zones Lapworth showed that the Upper Quartzite of Murchison was simply one or more zones of the Lower Quartzite coming to the surface from below the limestone and in places structurally overlying it as a result of inversion. In the Durness area he pointed out that along the junction of the quartzite-limestone series with the apparently overlying flaggy and micaceous schists (Moine Schists) there was 'excessive folding, wrinkling and inversion,' adding : 'the laminae on almost every slab from the schistose and gneissose rocks exhibit the most extraordinary wrinkling and puckering; while the geographical distribution of the petrological zones of the Durness Limestone can only be

satisfactorily interpreted upon the hypothesis that they are arranged in a number of flattened arches and troughs, whose very oblique axes all dip in one and the same general direction' (*Geol. Mag.*, 1883, Decade II, vol. X, p. 124).

It was in the Eireboll area, however, that his most striking results were obtained. He mapped and described the succession seen in the An t-Sron peninsula on the east side of Loch Eireboll and on the hill-slopes and ridge of the high ground to the east (Bealach Mhairi). He recorded the *ascending sequence* from Pipe Rock to the lowest sub-divisions of the Limestone, corresponding to the same divisions as seen at Durness ; the arrangement of the strata in a general synclinal form with the various lithological zones emerging on its eastern limb in their natural order ; the folding, convolution and in places inversion of the beds along this limb ; the *downward succession* that could be traced on the ground from zone to zone into the basal breccia upon the ridge behind. This detailed work demonstrated beyond doubt the identity of the lower and upper quartzites of Murchison and other previous observers and amply confirmed Nicol's view. Two conclusions followed :—(1) since palaeontological data assigned a Lower Silurian age to the quartzite-limestone series the gneiss on which the quartzite with its basal breccia reposed unconformably on Bealach Mhairi must be pre-Silurian ; and (2) as this gneiss was taken by Murchison to be part of his Upper or Eastern Gneiss and by Nicol as an intrusive rock of later date than the Eastern Gneiss the quartzite limestone series must be younger than the latter. He clearly showed that the ordinary evidences of superposition completely failed when applied rigorously to the Durness-Eireboll sections and that other criteria had to be invoked to explain them. These criteria he found in the principles of mountain-structure as developed by Heim and others to explain the structure of mountain-ranges elsewhere.

Lapworth's paper on ' The Secret of the Highlands ' appeared in the March, May and August numbers of the *Geological Magazine* for 1883. Further field-researches were stopped by illness and when he recovered the first results of the detailed mapping of the Durness-Eireboll region by the Geological Survey—begun in 1883—had been communicated to *Nature* in 1884. This work confirmed the main conclusions reached by Lapworth regarding the succession.

One further contribution which Lapworth made in 1884 to the study of the North-West Highland rocks outlines his views on the age, composition and mode of formation of the Eastern Schists (see ' Stratigraphy and Metamorphism of the Rocks of the Durness-Eireboll District,' *Proc. Geol. Assoc.*, 1885, vol. viii, p. 438 ; and *Geol. Mag.* Decade III, vol. ii, pp. 97–106).

In the later papers to which reference has been made Lapworth described the Eastern (or so-called Upper) Gneiss as composed of (a) an older portion, the Arnaboll Gneiss which he regarded as part of the Laurentian, brought up by large-scale overfolding and (b) a younger portion made up of the complex of schistose metamorphic rocks of eastern and central Sutherland. This younger series contains within it strips and wedges of the Durness-Eireboll Series, all so crushed and mechanically metamorphosed that they cannot be separated in the field. 'The Sutherland schistose series,' he writes, ' is composed of a complete intermixture of Archaean and Assynt rocks, the two series being so interfolded and interfelted together . . . that they must be mapped simply as " metamorphic."' He emphasised that there is ' no recognisable chronological sequence (or invariable order of super-position) in the metamorphic Highland area,' that the planes dividing the metamorphic rocks are ' planes of shearing and cleavage,' that ' many of the Highland schists are composed of Archaean rocks which have received their present pseudo-bedded arrangement since Ordovician times,' and that ' what proportion of these schists and gneisses is composed of Archaean, sedimentary, or intrusive materials respectively is in all probability an insoluble question.'

THE RISE AND DECLINE OF THE GREATER YAM IN THE SERVICE OF MAN[1]

by

I. H. BURKILL

DIOSCOREAS winter as a bud on a comparatively voluminous store of food; and the success of each year of life depends on keeping that store inviolate. To this end the various species protect it against destructive animals, such as wild pigs, which root for their food, and indeed against Man who as a food-gatherer can be even more destructive though armed with no more than a stick. Many load their tubers, the yams, with poisons; some provide a hard crust; some arm them with thorns; and some bury them under a forbidding depth of soil. *Dioscorea alata*, the yam proper, buries them and needs no poisons. The food in them is in amount and nutritive value as in the potato; therefore *D. alata* may be classed with esculents that give generous starchy tubers as the potato, the sweet potato, Colocasia and Manihot, and is their competitor in markets.

D. alata is so closely allied to the wild *D. hamiltonii* and *D. persimilis* that all three must have had a common ancestry and

[1] Substance of a paper given to Section H (Anthropology and Archaeology) at Birmingham on September 4, 1950.

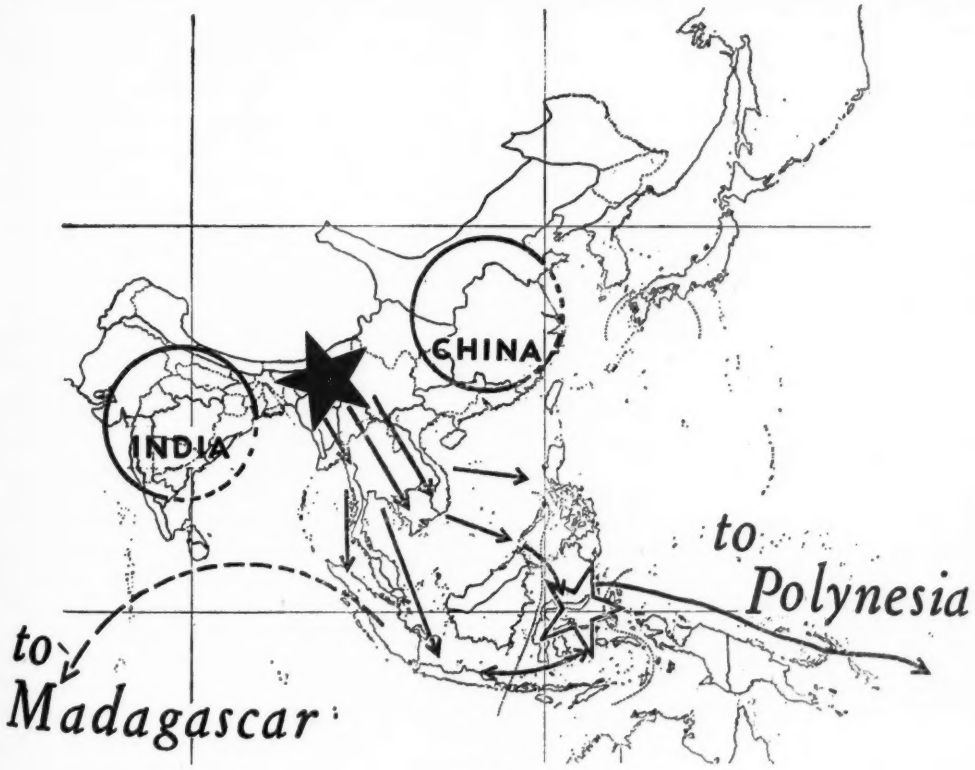

FIG. 1

home which the wild plants prove to have been where the black star is on Figure 1. *D. alata* has a more fleshy stem than the others (seemingly an accident in Man's selecting), a polymorphy of tuber which is a consequence of selection and some more or less significant characters of no immediate interest. The two wild species, driving their tubers down to six feet, find this depth of soil protective enough against the pigs ; and villagers are reported as being little tempted to dig for them systematically in spite of a small luxury value in the local markets. When Man made *D. alata* out of the common ancestry he had to free his charge from the insistent pig-pressure which kept and still keeps the wild species from varying successfully towards a diminished elongation of their tubers. Man invariably propagates his charge by replanting a part of the tuber, that is to say he keeps alive the one individual plant, and he has done this through all the centuries for each form (clone) that he possesses. When we look at one of them, we are looking back, wonderfully, through we do not know how much of the past. Plants would fruit at times throwing divergent forms ; and each clone now persisting is the individual that first attracted the attention of the cultivator who annexed it. The country of the black star on the map is full of clones that bury deeply, being near to the ancestry ; the country of the white star is full of clones with shorter tubers, branched tubers, fasciated, and tubers with their urge to descend altered (Fig. 2).

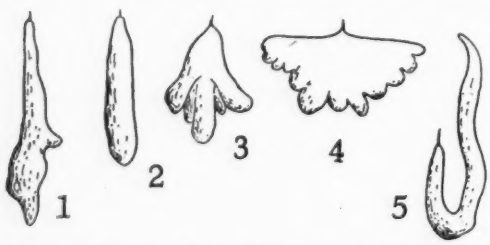

FIG. 2.—1, a yam from Assam, six feet in length ; 2, a yam from Fiji, such as is common there ; 3 and 4, short yams from eastern Malaysia ; 5, a snake yam from the Philippine Islands, its direction reversed in the soil. All drawn to the same scale.

This white star marks a secondary centre of ennoblement that could not but be late. We know that between the circles on the map which represent nascent India and nascent China there has been from remote times a great corridor of escape down which central Asia discharged superfluous tribes to jostle their way, as the arrows on the map suggest, southwards. They used shifting agriculture. Some tribe among them originated yam-cultivation which the general body carried from the black star to the white star ; at the same time it diffused laterally.

There are features in the cultivation of the Greater Yam which suggest that the habit originated among cultivators already partly graduated in horticulture. They are these : that the yam-harvest is brief and for other parts of the year there had to be reliance on other plants, on Colocasia for instance, which according to botanical evidence was taken into cultivation in the same part of Asia ; Colocasia was easier to grow, cropped before the yam and did so over more months. A full discussion would be long ; let it suffice, instead, to suggest that there were patches of Colocasia in the hollow whence the village drew water before there were garden beds within the protection of the village fence where yams could be raised on well-drained and therefore appropriate soil. Then, if this belief be entertained, the house that sheltered the cultivator prolonged the period over which he could enjoy the fruits of his labour by providing a store in which he kept tubers not immediately required. The curse of the food-gatherer is that he can keep nothing.

Yams keep excellently in store. When buried, the new bud shoots at its appointed time on the water in the tuber ; but exposed, it is subjected to just enough drying for the most forward apex in its bud to be checked in consequence of its outside position ; and the transfer to the leadership of another apex brings delay. That is the secret of the keeping ; and keeping qualities made the yam. We shall see later that they were responsible for its reputation as a vegetable for ships.

D. alata in its home receives rain over more than eight months : the remainder of the year is that in which it lies at rest and is harvested. As its home receives longer rains than all the surrounding country, its diffusion abroad meant

prolongation of its vegetative season by the provision of water. That service, added over and above to the simpler service of freeing it from competition, can and does raise the yam to the dignity of a luxury crop and gets it carried through physical barriers.

Indian literature preserves no mention of the yam earlier than the Susruta Samhita of A.D. 600 which indicates it to have become a common food, at least in the Gangetic plains where it could not have been general without provision of water. If common in the Gangetic plains, it was certainly wide in India ; and it seems safe to assume that it was accepted as now—that is in all parts towards the north-east, in decreasing quantity towards the north-west by reason of the dryness, in plenty through Malabaria and absent from the driest parts of the Deccan. I picture it as having entered India in the wake of Colocasia and see it as unable to extend quite as far as Colocasia could. We find that Colocasia appeared in the Levant at the commencement of our era when, because of its love of water, its use as food and the service of its leaves as platters, the Greeks classified it as a non-flowering kolokasion, in common with Nelumbium which was their first kolokasion. Arabs after 641 took it to Spain and caused it to spread through Guinea. Again it escaped from India westwards, getting to Yemen where it obtained the name sanj, to Zanquebar (now named m'sanga in Usambara) and to Madagascar (giving rise to the name saonjo). The evidence for this is linguistic, but seemingly adequate ; and the date when the Yemenite Arabs colonised southwards was from the eighth to the eleventh centuries. But the spread of the yam came to a dead end by reason of the aridity of the shores to which ships sailed westwards from India.

Here I take the reader back to the Corridor to follow the southward escape of these two esculents. But first let it be said that the Siamese Peninsula cannot have afforded a bridge for them into Malaysia, and that the southern China Sea was no bar, for on this sea travel by water had developed so early that Hornell gives reasons for thinking the outrigger canoe to have been devised about the mouths of the Menam and Mekong. Two unconnected things now happened :—(i) cultivators of yams who had come to rest on islands not overrun by pigs were able to keep short-tubered sports of the yam as they turned up, and (ii) India, more advanced than Malaysia, discovered Malaysia. In the last centuries B.C. amusing stories of adventurers who crossed the Bay of Bengal and, marrying naked princesses after teaching them to wear clothes, became rulers, circulated in India and passed into writing. This means that India, already competent in weaving, found a market for her cloth. The stories conveniently date the beginnings of Indian interference. Slowly the interference grew, but enduringly ; and the permanence of great kingdoms (Palembang kept touch with China, as the Chinese record, from the fifth to the fifteenth centuries) by requiring security in food supplies most clearly reveals an agriculture based on irrigated rice. These kingdoms grew entirely within the western half of Malaysia ; and the archipelago became divided into a West with rice and an East without. This abundance of rice in the West made the generous starchy tubers of less account and particularly the yam as it crops with the rice, while the absence of rice in the East promoted that development of short-tubered clones which has been mentioned. We have Rumpf's evidence of the years 1652 to 1692 over which he was busy with his Herbarium Amboinense, to the greater place in diet that the tubers had in the East and to current movements of men westward which took to Java some tuber-cultivating habits that would seem to have been lost there. It may be added that in the account of Javanese plants which his death in 1631 interrupted de Bondt found no place for the yam, though he mentioned Colocasia.

When the Hinduized Malaysian kingdoms were rising, but at an unascertainable date, certain migrants left Malaysia and moved eastwards until they found conditions in the longitude of Samoa which induced them to settle and let them radiate, as Polynesians, through all the eastern Pacific. It is not known whence they started, but a supposition that their origin was not east of Celebes would fit their case. They went without the technique of raising irrigated rice ; and only

one quite unsatisfactory legend connects rice with them ; but they relied on Colocasia for as many months' food as possible and had yams. To-day, here and there in the Pacific, Colocasia is a woman's crop and the yam a man's, being tabu to the women, not chivalrously because of the greater labour in raising it, but because the yams were wanted for voyaging which was a man's business. When the Polynesians settled in Hawaii they had ventured too far north for the best yams but not too far for Colocasia to which in consequence the greater esteem was given. When they settled in New Zealand they had gone too far south for the yam which, after trial, they abandoned ; and they found Colocasia to be possible only in the North Island ; so it was that they fell back on ferns for starchy food. But to them came a windfall when the sweet potato, having reached the eastern islands by an accident, was passed westwards. Then getting to Tahiti it was transported to Hawaii where Captain Cook found it to be the chief starchy crop. The Maoris say that they sent to fetch it from the central Pacific ; and dating this by their genealogies it may have arrived in Polynesia in the twelfth or thirteenth centuries. It arrived certainly by the drifting of a storm-driven raft from the American coast, as Hornell suggested and as Heyerdahl demonstrated possible in his recent voyage of the *Kon-Tiki*. In the central Pacific the sweet potato was accepted, but not preferred. It is stated that the natives of Guam would grow it for the Spanish ships which called regularly after 1564, but would not trouble with it for themselves. Climate, not preference, therefore made it so important to Hawaiians and Maoris.

The Malagassies came of another migration out of Malaysia which carried the yam to a new home. The Malagassy language has its nearest affinity in Toba Batak ; and this makes it clear that Madagascar was settled from the outer side of Sumatra. There is an Arab *Book of the marvels of India* of the date A.D. 945 which states that shortly before it was written certain ' Wakwak ' raided Madagascar for ivory, tortoiseshell, panther skins, ambergris and slaves. It happens that the Sea Gypsies of Tenasserim confuse Malays, calling them Bataks ; but there is no reason why an Arab should confuse them nor any why these raiders were not Bataks from Sumatra. If the raid familiarised Bataks with Madagascar, it might have been a prelude to their first settling. A second settling can be more precisely dated as in the fifteenth century, a reinforcement. The names for the yams grown in Madagascar, not merely the generic ' ovi ' which is from the Malaysian ' ubi ' and ' uvi,' but the adjectival words used for distinguishing the several clones, are almost all as recognisably imports from western Malaysia as any linguist might desire ; but there is no surety that the adjectives were in use before the reinforcement in the fifteenth century. The Malagassies at the time of the first visits of Europeans to their shores were relying very greatly on yams for their daily bread. Duarte Barbosa in 1516 recorded this, but using a corruption of the noun ' inhame ' by which the Portuguese denoted both yams and Colocasia, he is not quite as informative as could be wished. Cauche, who travelled up the east coast in 1638 gives eloquent testimony to the extensive consumption of the yams of *D. alata*. The Malagassies were growing rice, destroying wide areas by shifting cultivation and putting yams on the fallow of a rice field, let it be noted, as an agricultural, not a horticultural, operation. The Malagassies had introduced the word ' taho ' for Colocasia, taken from some form of the Malay name ' tales,' from which indeed the Polynesians had derived ' taro ' ; and they were likely to have brought Colocasia to Madagascar, but as stated above it would be there, also, by Arab activity.

In the year 1492 Columbus, making the first crossing of the Atlantic from Spain to the West Indies, fell in with bread made from Manihot and with fields of sweet potatoes. On returning home he exhibited to the Court (1493) the tubers of the latter. Nothing exists to indicate that they were planted and made good ; but without delay others brought more to Spain ; Spaniards, wrote Oviedo, would bring them and with luck get them across alive, but more often fail ; he had brought them himself in 1526. The plant became popular as a crop in Andalusia and locally

favoured in the Atlantic islands whence the tuber was traded to Lisbon and from Lisbon to London and the Low Countries ; but it would not stand longer carriage. Candied in slices and tinctured by boiling with Eryngium it was sold as an aphrodisiac. The Portuguese took the plant without delay to their stations on the west coast of Africa, as El Mina and São Thome, and round the Cape to Sofala and on to the Moluccas, lodging in all the ports their name ' batata.' In Malaysia the tuber made such an impression as to outrun the name batata and to be called kastela *i.e.* the yam of Castile, Spain and Portugal not being distinguished. About the same time the Spaniards took it to the Philippines direct from Mexico lodging with it a form of its Mexican name. Trusting Pigafetta's obvious familiarity with the plant as he had seen it in South America, we are bound to give credit to him in his statement that it was already in Guam in 1521. It would have reached Guam from the central Pacific. Possibly no plant has ever girdled the world in cultivation more rapidly than this novelty to Europe where there was nothing more like it than the unlike Skirret. It pleased many by its sweetness and all by the ease of its propagation and the rapidity of its growth. Robert Drury, prisoner in Madagascar from 1702 to 1717 and required to grow his own food, rather neatly expresses its place in the words ' the speediest thing that I could plant to produce myself food was potatoes.' It quickly outran its name batata on entering India by the Malabar coast and was known by descriptive names such as meant ' sugar tuber.' A three, four or five months crop, it could profit a peasant in some part of the year in any part of the land, a poor man's stand-by as it has become so transparently of recent years in northern China. In varying measure it reduces everywhere the call on the established starchy tubers at other seasons than the time of greatest rain.

By the route round the Cape which let the sweet potato into the Indian Ocean, the yam escaped out of it, and as early. It was a custom of the voyaging Portuguese to feed on native foods when in eastern ports ; they could not do otherwise ; and we have been told expressly that when starting for home, beyond biscuits, they were expected to bring their own food. One sees them, the stormy weather over and the native vegetable stalls full of yams, buying these because the native shipping took them ; and a very short time would suffice for the plant to be on the Guinea coast. The Spaniards and Portuguese were slave-dealing before Columbus ; and negro slaves were abundant in Portugal when the discovery of America opened an enormous market. This in turn led to a new trade, the trade of supplying food for the human cargo on the slave ships ; of this trade the Portuguese colony on the island of São Thome got the first share. Facing Nigeria and drawing slaves thence, we may be confident that originally the plantations on São Thome raised the Guinea Yam, *D. cayenensis* after the manner of the Ibos of Nigeria. But the Asiatic *D. alata* came, was tried and displaced *D. cayenensis*. We cannot tell how rapidly. There was a rebellion of slaves in Hispaniola at Christmas, 1522, of which Oviedo says that the slaves held out on the abundance of an imported yam. At 1522 it would presumedly be the yam of *D. cayenensis* which is plentiful still in the West Indies, though less so than *D. alata*. The first demonstration of the displacing was not made until Clusius was provided (1596) with tubers from a provisioned slave ship, and it does not date the displacing. It might have been well before 1550 for towards that date Ramusio contrived to obtain from a pilot staying in Italy, probably a fellow countryman, an account of the pilotage to São Thome in which four tubers used as food at sea are mentioned in order of their usefulness. As two of them were named respectively from Benin and the Congo, these were African ; the first and best, and the last and worst, remain to be identified. The worst, by its description, was the sweet potato—worst because it would not keep. The best would seem to have been *D. alata*, which became known in the trade as the yam of São Thome. If so, it had obtained its lead before 1550. Its great reputation for keeping, made it a sailor's vegetable ; and Philip Miller wrote in 1737 that he could readily replace in the port of London *D. alata* which he had lost from the Garden at Chelsea. Then, again, this

yam came into great demand during the Pacific Whaling Industry, the sailors whitewashing the tubers as they came aboard that the lime might act as an insectifuge and in their rough handling doubtless rubbing off any buds threatening growth.

We return to the other great vegetable which Columbus discovered, the Manihot plant, *M. utilissima*. Bread from it, or perhaps it were better called biscuit, was immediately adopted by the Spaniards; and the King of Spain soon had his storehouse in the West Indies whence departing ships received supplies—1,100 loaves, wrote Las Casas, for the boat in which he sailed for Europe (1522). But the Spaniards did not carry the plant alive to Europe. Its coming to the Old World is not documented, but can only have been by the Portuguese from Brazil to Guinea. Cavazzi da Montecucculo, unfortunately for our purposes publishing so late as 1690, connected its arrival with the island of São Thome. It is everywhere in Guinea now; and it cannot be absolved from the ruin of more good land than any other plant because it is the first thing that the indigent man plants when he clears forest for cultivation and it so rapidly exhausts the soil that the circle of felling moves the faster; moreover it advances that part of the population which contributes least to the common good.

Its entry into the Indian Ocean is very obscure. Tradition, as recorded in vernacular names, connects it in one or another part of Malaysia with every one of the trading nations who could have fathered it, and in Timor with Goa; but if the Portuguese introduced it as a vegetable into Goa, it was to insignificant effect, for records show that there was but little Manihot in Malabaria until 1885. On the other side of India towards the end of the eighteenth century, the East India Company brought in new stock which demonstrably led tribes about the borders of Bengal, too rude to indulge restricted food habits, to take to it in a way that must have reduced their reliance on Colocasia and in a less measure on yams. As in India, so in Malaya the rudest have been they who have been most ready for it. It is the first thing that a family of one of the wild tribes commits to the hazards of their inadequate plantation and is their bread to the extent to which they can come by it. The war-made famines of Malaysia in this century drove this vegetable of the lowest on to the tables of all; and great has been the extension of its use, not without considerable culinary ingenuity. I would make the point that it was Manihot and in no measure the yam that dire necessity put into the place of rice. Manihot has ended the kingdom of the yam in Madagascar. It is working its way into the Pacific. An economist now may feel that the yam slips out of his interests along with the wooden sailing ships that carried it; but he must not overlook this Brazilian root of almost phenomenal yield, for its tendency to alter the composition of a population and its destructiveness of a country's soil.

Latterly the potato has increasingly invaded the perimeter of the yam area in the East. In India it was once a hill crop that sent tubers to markets in the plains. Inevitably experimental plots appeared on the plains, where, in such measure as they have been encouraging, the old tubers lose in place. On the superiority in the kitchen of the potato over the yam there are no two opinions.

MIDLAND DRAINAGE:
SOME CONSIDERATIONS BEARING ON ITS ORIGIN[1]

by

PROF. DAVID L. LINTON

ANY attempt to discover the origin of the drainage system of the English Midlands may be said to have a two-fold object. On the one hand it may lead to a hypothesis which is helpful in understanding the present rivers of the region and so assist the geographer in his task of regional description and analysis. On the other, it may reveal something of the pattern of the river system in the phase of its inception and so throw light on the tectonic movements which brought it into being. Such light may be of assistance to the geologist in his task of palaeo-geographic reconstruction. It is hoped that both ends may be served in some degree by the present discussion.

We can, however, discuss such a topic profitably only if some elements of the original drainage have survived to be discussed. In view of the possibility that the initiation of the Midland drainage may date back to the beginning of Tertiary time —a matter of 50 to 70 million years—it may seem vain to hope for any such thing. This would indeed be so were it not for the fact that rivers, which are the agents which shape and destroy landscapes, commonly survive the changes they bring about. They tend to persist in their courses even though the hills through which they flow are reduced to the insignificance of a peneplane, and though the rock-formations on which they were initiated may have been washed entirely into the sea. True, the operation of river capture by the growth of strike streams along weak rock outcrops tends to replace the original drainage pattern by one better adjusted to geological structure. But where the rock structures do not particularly favour the growth of subsequent streams there is a chance that some of the original consequents may survive. Therefore we may look first in the bordering hard-rock uplands to find any survivors of the earliest drainage of the Midlands.

The Welsh Dee.

An older generation of workers, including W. M. Davies, S. S. Buckman, and H. J. Mackinder, believed that the drainage of much of southern and central England had originated on a surface of chalk tilted from N.W. to S.E. and that with the stripping of the chalk cover from Wales and the Midlands the original rivers became superimposed on the undermass, only to be later fragmented by the growth of subsequents on such soft rock outcrops as those of the Keuper marl and the Lias. This view has never been seriously challenged, but equally it has never been satisfactorily established. Professor Wills, writing after the lapse of half a century (1) finds it necessary to qualify his reference to ' the early south easterly drainage from North Wales ' by an ' if such existed,' but no alternative hypothesis has commanded even so much assent. It is therefore remarkable that when we search the uplands bordering the Midland region the oldest stream we can find does not possess the expected NW. to SE. direction. It is the eastward-flowing Welsh Dee.

From Corwen to the Cheshire plain below Llangollen the Dee flows in a deep narrow valley famed for its incised meanders. The tops of the isolated meander cores are at heights up to 880 ft. above O.D. and the Dee has thus been meandering here since its valley floor was at the 900-foot level—at a guess since early Pliocene times. The valley itself transects the north-eastern end of what is perhaps the most continuous upland ridge in Wales which stretches for fifty miles from the

[1] Paper read to the Geography Section at Birmingham on September 5, 1950.

shores of Cardigan Bay near Aberdovey through the Arans (2,970 ft.) and Berwyns (2,713 ft.) to Cyrn-y-Brain (1,844 ft.). above Wrexham (Fig. 1). At its western end this ridge is interrupted by several passes, but from the Arans north-eastward to Cyrn-y-Brain it is unbroken at the 1,600-ft. level save by the valley of the Dee. Beyond Cyrn-y-Brain the ridge gives way to generally lower ground and the main road A525 from Wrexham to Corwen has an easy route rising to only 1,089 ft. It goes without saying that had this lower route been open to the Dee when it first flowed east from Corwen it would have taken it in preference to the route entrenched into the upland. Hence it follows that the Dee has held its present course from Corwen by Llangollen since a time when its valley floor was at the level of the present upland surface around 1,800 ft.

A further point has to be made in relation to this deeply incised section of the Dee. Above Corwen the present Dee is a strike stream following a section of the Bala fault zone and clearly not original. But the Holyhead road A5 which has traversed the meandering defile of Llangollen continues its line directly westward by the open valley which at first carries the Alwen and the Ceirw, but which later, at Cerrig-y-Druidon, becomes virtually streamless. It is, however, still wide, open, flat, and mature and evidently once carried the main headstream of the Dee at an altitude about 900 ft. above O.D. from the territory further west now drained by the Conway. Two or three miles further on the drainage flows in the reverse direction and beyond the elbow bend of the upper Conway becomes deeply incised below the old valley floor. That capture has occurred is manifest, and the continuations of this

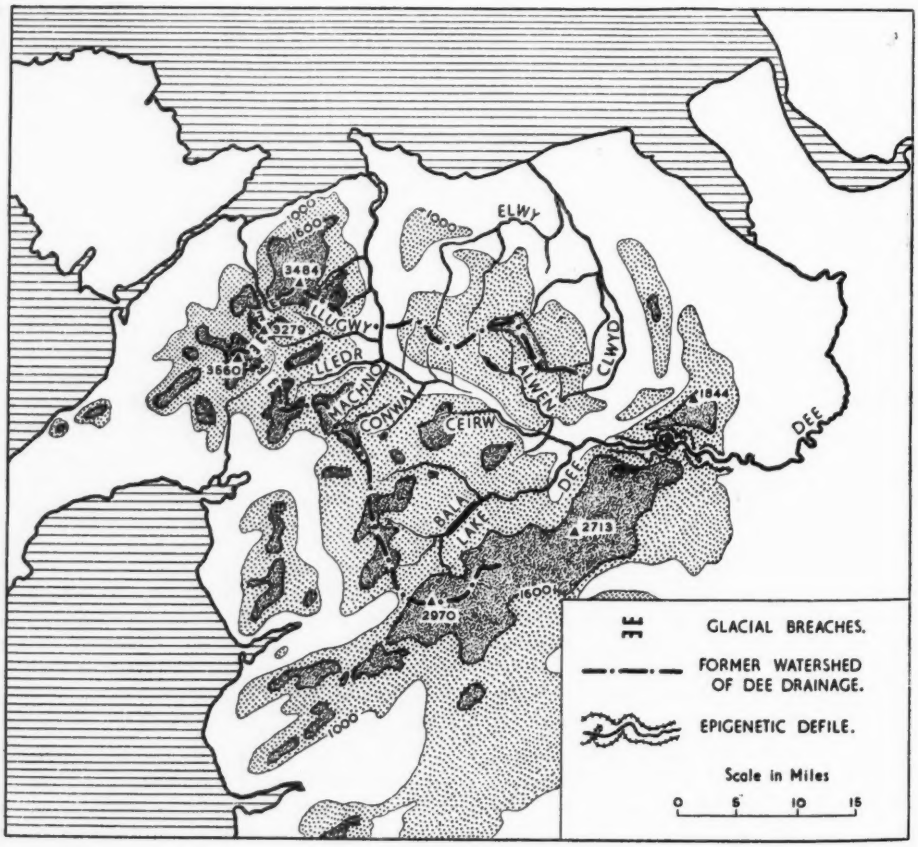

Fig. 1

former valley floor on the broad glaciated platforms above Bettws-y-coed at heights rather above 1,000 ft. are quite evident. In fact it is clear that before being decapitated by the invading Conway (and before glaciation breached the Snowdonian watershed at several points) the Dee drained all the eastern flank of the Snowdonian mountain mass from the Blaenau-Ffestiniog railway tunnel round to Llanrwst (Fig. 1).

The proto-Trent and its Pennine tributaries.

This reconstruction allows us to think that in later pre-glacial times the Welsh Dee carried water for over 40 miles from the flanks of Snowdon, first east-south-eastwards to Corwen and then eastwards by a flat-floored valley in which its meanders were as yet un-incised, to the Cheshire plain. It follows from this that at the still earlier period represented by the 1,800-foot surface of the Berwyn summits it had the same course. This may very well carry us back some 30 million years into earlier Tertiary time, and it is probable that we are here dealing with an original stream. If so, where did it go?

There can be no two answers to this question. Thirty miles east of the point where the Dee makes exit from the Welsh upland the infant Trent begins its course through the Triassic lowland towards Nottingham. Common sense suggests at once that the Dee was the former head of some proto-Trent which flowed eastward, not in any precise way along the course of the present Trent but probably over the site of Needwood Forest, heading for the gaps through the Jurassic and Cretaceous cuestas at Ancaster and the Wash. Probably the Welsh headwaters of this proto-Trent would be diverted to the Irish Sea by a strike stream across the Cheshire plain before the plateau gravels of Needwood Forest were laid down, and certainly before the present Ancaster gap was cut. But the Ancaster and Wash gaps may have been cut by the beheaded lower portion of our proto-Trent (for that would still have been a stream comparable in size to the modern Nene or Welland) and they are at least suggestive of the route by which it is envisaged that Snowdonian rainfall once reached the earlier-Tertiary North Sea.

Confirmatory evidence of such an eastward-flowing trunk stream is afforded by a consideration of the other major upland bordering on the Midland region, namely the southern Pennines. Here a series of streams, for the most part deeply incised in the upland, flow in south-south-easterly courses, often with epigenetic relations to the underlying geological structures. They are the upper Trent (at and above Stoke), the Churnet, Dove, Derwent and Erewash, and of these the Derwent is much the longest and displays most strikingly its epigenetic relationship to the structure of the upland. This relationship has too often been overlooked or ignored and is therefore worthy of more detailed notice. The general course of the river lies broadly parallel to the strike along the eastern side of the Derbyshire dome and Fearnsides states that ' the River Derwent may be fairly described as a subsequent or strike stream—its valley a trough separating the limestone plateau of the High Peak country from the dominating ridge of gritstones of the South Pennine and Derbyshire moors ' (2). He makes his view of the origin of the Derwent even clearer when he says that ' post-Miocene time has been long enough for the cutting back of the main stream's valley forty miles, from Derby to Bleaklow, mostly in the shale measures between the limestones and the grits ' (3). Yet in the same paragraphs he insists on the discordant relations between the river and ' half-a-dozen well-marked transverse tectonic folds,' and states that ' in crossing these anticlines and synclines the river has cut into every kind of rock in the succession between the top of the Millstone Grit series and the Upper Toadstones of Matlock some 600 ft. down in the limestone.' He has to conclude that ' the Derwent is no better than an average strike stream ' which has been locally superimposed. The fact is that there is no case at all for regarding it as a subsequent stream which has grown up along the outcrop of ' the shale measures between the limestones and the grits.' It is rarely in any outcrop that could fairly be so described and from Bamford to Belper, apart from its justly famous excursion into the limestone at Matlock, spends most of its time cutting through one or other of the gritstone outcrops. The river, as we see it below Bamford, is clearly superimposed

and if it be urged that it was a subsequent stream before it was superimposed, it must be retorted that it could only have been a subsequent stream following the strike of some now vanished outcrop at a level higher than the surrounding hills and not less than a thousand feet above the present valley. This would in any circumstances be an extravagant assumption but must be discarded here since it does nothing to explain the community of direction and discordance to structure which the Derwent shares with the other S.S.E.-flowing Staffordshire and Derbyshire rivers. No explanation seems so satisfactory as that which regards all these streams as former left-hand tributaries of our proto-Trent, superimposed while still relatively young upon an undermass of palaeozoic rocks.

The Midland Watershed.

At this point it is worth noting that there is an obvious analogy between the drainage system of the proto-Trent which we have just indicated, and that of the Kennet-Thames system adumbrated more than fifty years ago by Davis (4), and taken up by Buckman (5). In both cases a major longitudinal consequent is hypothecated, flowing eastward from Welsh sources to the North Sea (Fig 2). In both cases a number of the supposed transverse consequent left-hand tributaries flowing from N.N.W. to S.S.E. appear to have survived where superposition has let them down on to hard-rock uplands. The streams of the southern Pennines just enumerated may be matched by the Cotswold tributaries of the present upper Thames heading in wind-gaps that indicate their former extension over the Triassic lowland, the right-bank tributaries of the present middle Severn (Teme and Leadon) which make epigenetic crossings of the Malvern axis (6) and the manifestly superimposed Wye, Monnow, Usk, Taff, and other rivers in south-east Wales. In both cases, moreover, the system must be presumed to have been disrupted by the growth of strike streams along the soft-rock outcrop of the Lias when that formation became exposed in the Cheshire lowland and Vale

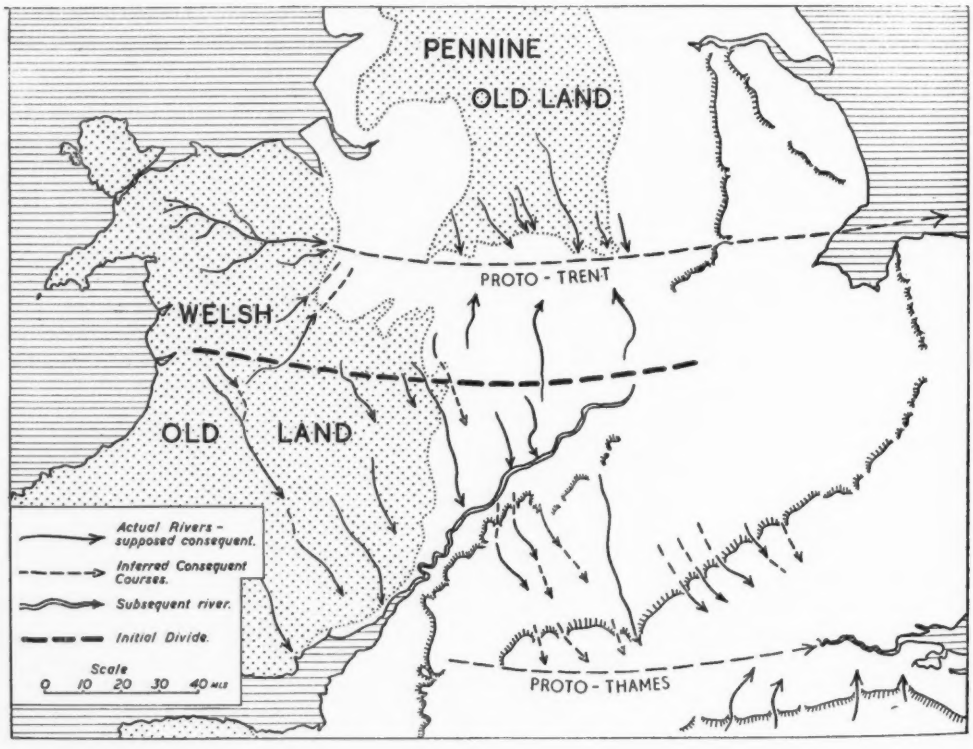

Fig. 2

of Trent in the northern case, and the Severn estuary and Avon valley in the southern. Although the Davis-Buckman view of the relations of the Kennet-Thames and the Welsh rivers was ridiculed by Strahan in 1902, it has been very generally accepted as a working hypothesis by later writers. The hypothesis of a proto-Trent now advanced is in evident harmony with the older and generally acceptable hypothesis of a proto-Thames.

The question, however, arises as to the nature and location of the watershed between the affluents of these two longitudinal consequents. The Welsh Glan, Wye, and Ithan, the Clun and Onny of the border country, and the Stour, Arrow, Swift and Avon in the Midlands may well represent some of the heads of the original southerly drainage to the Kennet-Thames and collectively they suggest an original waterparting along a line roughly passing through Plynlimon and Birmingham to Market Harborough. Now it is significant that immediately to the north of this line is a zone of northward flowing streams —part of the Vyrnwy, the Severn in the Vale of Powys, the Staffordshire Penk, the composite Blyth-Tame, the Leicestershire Soar and the north-eastward flowing Welland. The last named is possibly exceptional and its course to be explained, like certain other anomalous drainage features of the East Midlands, on quite different grounds. But the remainder appear to the writer to constitute a single family of streams united in their possession of a common direction which is unusual in British drainage systems. Significantly enough this direction is matched elsewhere only in what may be comparable circumstances : There are northward-flowing streams in Dorset and the Isle of Wight which are held to be surviving consequent tributaries of the former longitudinal consequent Frome-Solent (7); there are the well-known northward-flowing streams of the North Downs flowing to the longitudinal consequent Thames ; and there are northward-flowing streams in the south of Scotland which are held to be surviving consequent tributaries of the longitudinal consequent Tweed (8). It is not claimed that the north-flowing streams of the Midlands would by themselves be recognised as remnants of an original consequent drainage: they are neither numerous enough nor sufficiently uniform in character or direction. But the presence of a group of streams with a common and unusual northward direction of flow in this latitudinal zone immediately south of the line of a hypothecated longitudinal consequent is surely of considerable significance. And in explanation of their fewness it is to be remembered that super-imposition of an originally numerous family on the predominantly weak rock outcrops of this zone would have led to the elimination of several less favourably placed streams.

It will be seen that the glacial diversion of the whole of the upper Severn through the Ironbridge gorge, amply demonstrated a generation ago by Wills (9), serves only to confirm the view expressed here. Until that event occurred a continuous but zigzag watershed could have been traced from Plynlimon to Leicestershire, and it is important to note that the bulges in that watershed were precisely where they might be expected—northward round the head of the soft-rock lowlands drained by the synclinal Stour and the subsequent Avon ; southward round the head of the partly subsequent Severn which appears, near Llanidloes, to have captured some former headstreams of the Wye ; and southward in Warwickshire where the north-south syncline which preserves the Lias near Solihull appears to have favoured the extension of the Blythe. The sinuosities of this watershed thus have the appearance of expectable migrations of the divide locally away from an initial waterparting determined by an east-west zone of warping or uplift.

Some Tectonic Consequences.

Thus far the argument has been geomorphological. From data which are observable and verifiable in the field we have sought to classify the streams of the Midland region (using that term in a very wide sense) and to identify those which may be presumed to have survived from the period in which the drainage was initiated. In this way the elements of a system have been made out which appear to have been of the same general pattern as the Kennet-Thames system to the south and separated from it by an east-west initial watershed. If these conclusions be

accepted it is necessary to go forward and examine their consequences in the field of tectonic evolution. Some of these consequences are set down in the paragraphs that follow.

1. The evidence of superposition of the drainage from a vanished cover on to an undermass of unrelated structure is so widespread and consistent—we have here noted it in North Wales and the southern Pennines and it has been recorded by other workers in South Wales and the Malverns and by the present writer in south and central Scotland—that it seems impossible not to conclude that the drainage of the whole region from South Wales to the Pennines, and perhaps to central Scotland, originated by superposition from a single widespread cover formation at a single epoch. If this conclusion be accepted there is only one rock formation which possibly could have played the role of cover rock, namely the Chalk.

2. Older ideas that the drainage of Britain originated on a surface tilted toward the south-east must be abandoned, and instead it is possible to envisage a deformation of that part of Britain lying between the parallels 51° 30′ and 53° 30′ N. giving rise to two major consequents (the proto-Thames and proto-Trent) flowing directly eastward to the North Sea depression. This view is consonant with the conclusions reached for Scotland by Bremner (10) and by the present writer (11), for the north of England by Trotter (12), and with the ideas regarding the rivers of Yorkshire developed by Cowper Reed in 1901 (13), though in certain respects these now stand in need of re-examination.

3. The recognition of tributaries to the proto-Trent and proto-Thames flowing northward on the right-hand and south-south-eastward on the left implies the development of east-west upwarps in addition to the main west to east tilt.

4. It has been rather generally assumed that the drainage of the English plain was initiated by the mid-Tertiary movements that folded the Oligocene strata of the Isle of Wight. But several converging arguments suggest that this view is incorrect.

(a) The surface inequalities produced by the original deformation of the Chalk are known to have been large, since 1,000 ft. of chalk were removed from the London area (14), and probably more from the Midlands and the Weald, before Eocene times. It has yet to be demonstrated that, in the area north of the Kennet-Thames, any later movements have been strong enough to dislodge the pre-Eocene rivers from their courses, except in the London Basin where a *tabula rasa* was provided by the Pliocene transgression.

(b) The pattern of the mid-Tertiary movements in eastern England is writ large upon the geological map. As everyone is aware the outcrop of the base of the Chalk reaches its most easterly position in Norfolk, and north of the Wash turns north-westwards so that the Lincolnshire and Yorkshire Wolds duplicate the Chilterns as far west as the meridian of Princes Risborough. Between that meridian and west Norfolk the outcrop is bowed eastward a matter of nearly sixty miles—a result which must be attributed to post-Cretaceous deformation about an east-west axis through Norfolk and the Midlands. But this axis must also be post-Eocene (since on its southern limb it controls the Eocene as well as the Cretaceous outcrops) and so is presumably mid-Tertiary. The river system that would have appeared had this movement deformed a truly plane surface would have radiated north-east, east and south-east from Leicestershire. It clearly has no relation to the proto-Trent system we have here outlined. The latter is presumably older.

(c) The Welsh Dee is older than the erosion surface represented by the Berwyn summits. Our knowledge of Welsh denudation chronology does not yet allow us to date this surface but if, as the available evidence appears to suggest, this surface is older than the mid-Tertiary movements, the Dee, and hence the proto-Trent system as a whole, must be older still.

It is therefore concluded that the proto-Thames and proto-Trent systems arose from the pre-Eocene deformation of the Chalk and afford the best evidence yet to hand regarding these movements

outside the areas where Tertiary deposits are still preserved.

5. Wills has assumed (15) that the deformation of the Mesozoic cover of the Midlands occurred late enough to cause 'a major modification of the original lay-out of the drainage as envisaged in the Davis-Buckman hypothesis.' This seems extremely doubtful.

(a) On the one hand, it is proper to assume (until good evidence is brought forward to the contrary) that the relation of the Chalk to the upfolds and basins of the Mesozoic undermass in Cheshire and Staffordshire was not dissimilar from that now visible between the Chalk of Yorkshire and the structures in the underlying Jurassic rocks. The Market Weighton axis and the north Yorkshire trough are major structures whose growth was essentially contemporaneous with the deposition of the formations they affect, and the post-Kimmeridgian faulting that is so conspicuous in the Howardian Hills is part of the British expression of the Saxonian phase of crustal movement that was widely developed in Central Europe and is everywhere pre-Upper-Cretaceous.

(b) On the other hand, incomplete though the surviving remnants of the proto-Trent system admittedly are, they have a unity and consistency and a degree of similarity to the better-preserved proto-Thames system that argues against its framentation by diastrophism. The operations of river capture as soft-rock structures became exposed in the undermass appear quite adequate to account for the fragmentation observed.

It is a corollary of the view here adopted that when the Dee flowed over the Berwyn summits which are now close on 2,000 ft. above sea-level it passed out into the plain of north Shropshire without significant change of level, and hence that upwards of 1,600 ft. of Jurassic strata must have been present in the centre of the syncline where the Lower and Middle Lias are still preserved around Prees. A comparable thickness would have occupied the synclinal trough east of Birmingham which also preserves Lias to this day. Figures for the thickness of Jurassic rocks up to the Cretaceous cover before the latter was removed· were presumably still greater.

6. Finally it is possible to envisage the eastward tilt that produced the proto-Thames and proto-Trent, and the ancestors of the Aire-Humber, Tyne, Tweed, Forth, Earn, Dee and Don in a larger relationship. It may be recalled that about ten years ago Cloos included the area of Great Britain and Ireland among his dome-shaped elevations which he found were associated, after a certain stage in their development, with rifting and vulcanicity (16). The plateau lavas of Antrim and the Hebrides, which have been preserved by being warped and faulted down below middle- and later-Tertiary base-levels, mark the northern end of his meridional rifted zone: the southern is suggested by the roughly parallel-sided trough whose sides descend sharply from the 30- to the 50-fathom line beneath the western Irish Sea. The results of a thorough exploration of the sea bottom in this zone by modern methods would be of the greatest interest. It is possible that Cretaceous rocks may be preserved there in down-faulted strips and that it is from such outcrops that the relatively abundant flints of the Wexford drifts have been derived.

However that may be, it is noteworthy that the views here advanced as to the early consequent drainage of much of Britain appear to be fully consonant with Cloos's hypothesis. Not only have the main streams the expectable eastward flow broadly perpendicular to the zone of rifting, but they originate at the right moment in time. Doming is gradual and precedes rifting and vulcanism, and its earlier phases are perhaps evidenced by the eroded Jurassic and attenuated Cretaceous successions of Antrim and the Hebrides and the absence of the Turonian stage from both. After Senonian times doming became definitive and our consequent rivers may be assumed to have been in existence when the Maastrichtian and Danian Chalks were being laid down elsewhere. In Eocene times the effusion of the plateau basalts began and foundering ensued. With it would come into existence some of the westward-flowing

rivers of Great Britain whose tributaries have been actively engaged in capturing territory from the eastward-flowing drainage ever since.

REFERENCES

(1) Wills, L. J. 1948, *The Palaeogeography of the Midlands*, 101.
(2) Fearnsides, W. G. 'The Geology of the Eastern Part of the Peak District.' 1932, *Proc. Geol. Assoc.*, **43**, 155.
(3) *ibid.*, 177.
(4) Davis, W. M. 'The Development of Certain English Rivers.' 1892, *Geogr. Journ.*, **5**, 127–146.
(5) Buckman, S. S. 'On the Development of Rivers.' 1899, *Nat. Science*, **14**, 'River Development,' 1902, *Geol. Mag.*, 366 and 378.
(6) Wills, L. J. *op. cit.*, 99.
(7) Wooldridge, S. W. & Linton, D. L. 'Structure, Surface and Drainage in S.E. England.' 1939, *Trans. Inst. Brit. Geographers*, no. 10, Figs. 19 and 20.
(8) Linton, D. L. 'The Origin of the Tweed Drainage System.' 1933, *Scot. Geogr. Mag.*, **49**, 162–175.
(9) Wills, L. J. 'The Development of the Severn Valley in the neighbourhood of Iron-Bridge and Bridgnorth.' 1924, *Quart. Journ. Geol. Soc.*, **80**, 274–314.
(10) Bremner, A. 'The Origin of the Scottish River System.' 1942, *Scot. Geogr. Mag.*, **58**, 15–20, 54–59, and 99–103.
(11) Linton, D. L. 'Some Aspects of the Evolution of the Rivers Earn and Tay.' 1940, *Scot. Geogr. Mag.*, **56**, 1–11 and 69–79.
(12) Trotter, F. M. 'The Tertiary Uplift and Resultant Drainage of the Alston Block and Adjacent Areas.' 1929, *Proc. Yorks. Geol. Soc.*, **21**, 161–180.
(13) Reed, F. C. 1901, *The Geological History of the Rivers of East Yorkshire*. London.
(14) Wooldridge, S. W. and Linton, D. L. 'Some Episodes in the Structural Evolution of S.E. England.' 1938, *Proc. Geol. Assoc.*, **49**, 264–291, Fig. 52.
(15) Wills, L. J. *op. cit.*, 1948, 100–101.
(16) Cloos, H. 'Hebung, Spaltung und Vulkanismus. 1939, *Geol. Rundschau*, **30**, Zwischenheft 4A, Stuttgart.

INDUSTRIAL USES OF RADIOACTIVE ISOTOPES[1]

by

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SINCE radio-isotopes became freely available in this country some eighteen months ago, the benefits to industry from the applications of radioactive isotopes produced in nuclear reactors has grown steadily and is increasing rapidly.

Some radioactive isotopes were available when accelerating machines such as cyclotrons started to operate, though the material so produced was scarce and expensive. In 1946 the Americans released radioactive isotopes produced in nuclear reactors for medical and research purposes, and in 1947 we were able to make a few radioactive isotopes in our small pile.

When in March 1949 the bigger Harwell Pile (BEPO) started to operate on high power, it was possible to produce radioactive isotopes in large amounts and with relatively high specific activities. From that date onwards radioactive research material was available, so that these new tools of science could be used for scientific and industrial research as well as for medical purposes. During the 18 months the bigger pile has been in operation more than 6,000 shipments of radioactive isotopes have been made to 24 countries. The production of these isotopes is relatively simple. The target material is inserted into aluminium cans which are put into graphite stringers and then the graphite stringers are placed into the pile. The activity induced by neutron bombardment is a function of the half life of the isotope created, the cross-section, the irradiation time and the neutron flux.

[1] Substance of a paper given to the Physics Section at Birmingham on September 1, 1950.

Some very important isotopes have, unfortunately, a relatively low cross-section which results in them obtaining only a relatively low specific activity. For a number of research purposes they are not suitable without enriching the active material. From the industrialist's point of view, iron is one of these elements where such an enrichment is necessary after the irradiation. A number of chemically concentrated isotopes, including iron, are now being prepared and there are only a very few isotopes left which cannot, at present, be readily produced with high enough specific activities.

High specific activities are needed for the application of isotopes in research in two ways. By making use of the easy tracing of radioactive material, a method using radio isotopes would only have an advantage over other orthodox methods if the tracing can be followed further, which means the dilution measured can be greater. One ten-thousandth to one-thousandth of a microcurie of activity can be detected and, starting with 10 mc of material, this would mean that a dilution of 1 in 10^7 to 10^8 can easily be followed quantitatively. One ten-thousandth of a micro-curie of I^{131} (8 day half life) represents 10^{-15} g., which gives a lower limit for the smallest detectable amounts involved in tracer experiments.

Such dilution experiments are relatively easy on a laboratory scale, but for most experiments with larger quantities, limits are usually given by the amounts of radioactive material available, and the health hazard involved when using strong sources. Let us take one concrete example. A lake containing 50 million gallons of water is suspected of having direct connection to coal pits. The task is to ascertain if such a connection exists in order to find out if it is necessary to pump dry the lake.

Taking the figure given above of one-thousandth of a microcurie as the limit of detection and assuming that this amount should be in a liquid counter holding 10 ml, and should double the background, an amount of 10 curies of active material would have to be distributed evenly in the lake. By reducing the volume of the sample by evaporation, this sensitivity can easily be increased by a factor 100. It is possible to produce these activities in, say, 1 Kg. of a sodium salt, though the necessary health precautions have to be taken. One of the main difficulties in this case would be to distribute the active material evenly in such a big volume of water. Such an experiment is envisaged and could be tried as it is certainly more promising then any dye which can be used for this purpose, as dyes are firstly easily adsorbed on the soil and secondly their detection is less sensitive.

Experiments where the detection has been possible in even bigger dilutions are, for example, the measurement of oil on nylon fibres. Normally, on an average yarn, the weight of oil is about 10^{-6} grams/cm. and by weighing, it is only possible to determine the average weight over a considerable length of yarn. By adding to the oil an organic compound containing radioactive bromine, it was possible to detect 10^{-10} grams of oil per centimetre. This sensitivity could have been easily stepped up by another factor 10. The additional advantage in this case was the possibility of measuring the distribution of the oil, which was done by determining the activity with an X-ray film.

Experiments have been done to measure the rate at which the bearings of pumps wore under conditions of bad lubrication. The bearing was irradiated and the activity measured in the lubricating oil by immersing an X-ray film. With such methods and the present available neutron flux, it is possible to determine a tenth of a milligram of iron per litre of lubricating oil and even this figure can be improved by concentrating the iron debris in the oil.

Use of easy detection of gamma rays has been made in quite a number of cases. Pieces of radio-cobalt have been placed in the earth as markers for agricultural research purposes.

The cleaning of long pipelines is often performed by sending through the line a metal scraper which is liable to get stuck. It is a cumbersome task to find the place where the stoppage occurred. This problem can be solved by making the scraper radioactive.

At a Gasification Research Station in this country, the gamma rays of cobalt have been used to solve the problem of

making an underground connection between two pipelines. The holes were put from different directions in a coal seam and it was desired to determine the two points in the holes nearest to each other and to give an estimate of their distance underground. This experiment was easily done by using a 500 mc cobalt source with a window in lead shielding which was inserted in one hole and a detector into the other hole. The nearest points were determined, the distance estimated and an explosive charge made the desired connection.

The exchange of air in a room can be checked by following the removal of a radioactive gas or vapour which has been released in that room. A similar experiment has been done in order to check the removal of a volume of air in a factory, where dust particles were produced. A suspicion arose that not all the dust particles were sucked through the existing duct system and a release of 300 mc of radio bromine contained in an organic compound established fairly accurate figures on how much of that air, which was supposed to go through the duct system, remained in the room, and at the same time an estimate could be made of the concentration of fouled air at various places. The system of collecting the vapour was by sucking at a defined rate through wash bottles filled with a proper absorbing medium.

The efficiency of mixtures can easily be followed by adding small amounts of a radioactive material. Such an experiment showed, for example, that one gram of vitamin was, in a certain type of mixer, being equally mixed in five tons of cattle food. The activity was measured on the conveyor belt after the cattle food had left the mixer. The radioactive isotope was the short lived sodium.

At the British Industries Fair in May, 1949, the Atomic Energy Research Establishment showed thickness (or better—weight per unit area) gauges, using radioactive beta emitters to control the thickness of material being rolled in the production process. Such instruments have since been developed by different firms in this country. They are now on the market and are already widely used in industry. More recently thickness gauges have been developed which are able to measure thin layers of varnish, paint or tin on iron by a method which makes use of beta back-scattering.

An empty package detector using beta emitting isotopes was an exhibit at the British Industries Fair, 1950. Such a machine can detect the incomplete filling of a package and one firm is already offering such empty package detectors in an adapted form for different purposes of detecting incomplete packing.

The elimination of electrostatic electricity is a great problem in many branches of industry. Difficulties in the manufacture arising from the charges on the material to be processed as well as the fire hazard connected with these high charges, make it desirable to dissipate the electricity at the same rate as it is built up. By ionising the surrounding air where these charges are built up, it is possible to make the air conducting and so dissipate the electrostatic electricity. The highest ionisation per volume is obtained by using an alpha emitter, but a lack of alpha emitting material made it necessary for us to use beta emitters for this purpose. Though the activities used to dissipate a certain charge will have to be much higher than the ones if alpha active material would be available, the beta emitter has, however, the advantage of ionising the air over a much bigger volume. Strips containing radio-thallium, a long-lived beta emitter, are being made experimentally at Harwell and are given out on loan to firms. The Radiochemical Centre, Amersham, is now preparing rolled foils containing thallium which can be used as sources of weak ionisation which are big enough, however, to be of use in certain industrial processes.

I have tried to explain some representative experiments from the more than 100 applications which Harwell has developed or helped to develop for industry. There is, however, a big difference in what has been done in this field and what could be done. Although very big efforts have been made to help industry, the number of enquiries received were relatively small. In my opinion, it was perhaps excusable that industrial firms should be reluctant to embark on a big new isotopes programme although this excuse

may hardly be valid for firms with big research departments. It is in the industrial research laboratory where isotopes will be of more immediate benefit than the more complicated uses of isotopes in process control, except the gadgets mentioned in this article. Now enough initial work has been done in this field to show its usefulness over a very wide area and all the necessary tools are readily obtainable. Detection and monitoring equipment, radioactive material and expert advice from Harwell, as well as from private firms, are available and even a training school to teach the new techniques involved will start this year at Harwell. It would hardly be excusable any more for firms to continue to neglect this new and important research tool. I am convinced that in a few years the research of atomic energy will have benefited civilisation in the industrial field as much as it has already done in medicine.

REFERENCES TO PUBLICATION OF COMMUNICATIONS TO THE SECTIONS

AND OTHER REFERENCES SUPPLIED BY AUTHORS

(As at Jan. 31)

The following matter refers to the papers delivered to the Sections as recorded in *The Advancement of Science*, No. 27, p. 351.

The titles of discusssions, or the names of readers of papers, as to which publication notes have been supplied, are given below in alphabetical order under each Section.

References indicated by 'cf.' are to appropriate works quoted by the authors of papers, not to the papers themselves.

Section A

Application of atomic piles to experiments in nuclear physics, 1950 *Nature*, **166,** 506.

Bacon, G. E. Cf. 'X-ray neutron diffraction by graphite layers,' 1950 *Nature*, **166,** 794; 'Some mechanical features of a double crystal neutron spectrometer' to appear in *J. Sci. Instruments*.

Calvert, E. S. 1950 *Nature*, **166,** 683. Cf. 'Visual aids for low visibility conditions' *J. Roy. Aero. Soc.*, July, 1948; 'Visual aids for landing in bad visibility' 1950 *Trans. Illum. Eng. Soc.*, **15,** No. 6.

Civil applications of atomic energy, 1950 *Nature*, **166,** 535.

Cockcroft, Sir John. Cf. *The development and future of atomic energy* (Romanes Lecture), Oxford, Clarendon Press, 1950.

Cooper, Dr. J. L. B. Expected to appear in *Mathematical Gazette*.

Dating the past, 1950 *Nature*, **166,** 756.

Eastwood, W. S. Cf. 'A survey of pile-made isotopes for industrial radiography' M. of S., Harwell, No. A.E.R.E. I/R 386.

Goward, F. K. Cf. 'Photo-disintegration of oxygen into four alpha-particles' 1949 *Proc. Phys. Soc.* A, **62,** 460 and **63,** 1173; 'Photo-disintegration of carbon into three alpha-particles,' 1950 *Proc. Phys. Soc.*, A, **63,** 402.

Heat flow in the earth's crust, 1950 *Nature*, **166,** 974.

Hibbard, Dr. L. U. 1950 *Nucleonics*, **7,** No. 4, 30–43.

High energy particles and machines for their acceleration, 1950 *Nature*, **166,** 580.

Lighting of galleries and museums, 1950 *Nature*, **166,** 637.

Rawson-Bottom, W. E. *Museums J.*, Nov. 1950.

Section B

Chemical energy, 1950 *Nature*, **166**, 669.

Happey, Dr. F. To appear in *Brit. J. App. Physics*.

Hunter, Dr. R. F. Part expected to appear in *Trans. Soc. Chem. Ind.*

Melville, Prof. H. W. 1949 *Proc. Roy. Soc.*, A, **199**, 1.

Percival, Dr. E. G. V. Cf. 1943 *J. Chem. Soc.* 51 ; 1947 *Ibid.*, 1622 ; 1949 *Ibid.*, 3041 ; 1950 *Ibid.*, 720, 827 ; 1950 *Nature*, **166**, 787.

Taylor, Dr. J. Cf. 'Low temperature combustion reactions in the solid state,' 1948 *Industrial Chemist*, **24**, 289 ; 'Ammonium nitrate as a solid fuel to provide gas for propulsive purposes,' 1949 *Third Symposium on combustion, flame and explosion phenomena*, Williams and Wilkins, Baltimore.

Section C

Anderson, Prof. J. G. C. Expected to appear in *Trans. Roy. Soc. Edinburgh*. Cf. 'Stratigraphical nomenclature of Scottish metamorphic rocks,' 1948 *Geol. Mag.*, **85**, 89–96.

Concealed coalfields of the English Midlands, 1950 *Nature*, **166**, 505 ; 1950 *Colliery Guardian*, **181**, 376.

Fearnsides, Prof. W. G. 1950 *Colliery Guardian*, **181**, 376.

Lamont, Dr. A. Expected to appear in *Quarry Managers' J.* Cf. 'Fossils from Middle Bunter Pebbles collected in Birmingham,' 1946 *Geol. Mag.*, **83**, 39–44 ; "Illustrations of Derived Fossils in Middle Bunter Pebbles from the Birmingham and Warwick Districts', 1948 *Quarry Managers' J.*, **32**, 87–96.

Phillips, Dr. F. C. Cf. 'Apparent coincidences in the life-history of the Moine Schists' expected to appear in *Geol. Mag.*

Rhodes, F. H. T. Expected to appear in *Phil. Trans. Roy. Soc.* (B).

Section D

Carthy, J. D. To appear in *Behaviour*. Cf. 'Odour trails of *Acanthomyops fuliginosus*, 1950 *Nature*, **166**, 154.

Edney, Dr. E. B. To appear in *J. Exp. Biol.*

Ellis, Dr. Peggy. Cf. 'Marching in locust hoppers of the solitary phase,' 1950 *Nature*, **166**, 151 ; 'Marching behaviour of hoppers of African migratory locust in the laboratory,' *Anti-Locust Research Bull. No. 8.*

Kennedy, Dr. J. S. To appear in *Phil. Trans. Roy.* Soc. (B).

Lees, Dr. A. D. Cf. 'The water balance in *Ixodes ricinus* L.' 1946 *Parasitology*, **37**, 1 ; 'Transpiration and the structure of the epicuticle in ticks,' 1947 *J. Exp. Biol.*, **25**, 379.

Locusts and grasshoppers, 1950 *Nature*, **166**, 625.

Neal, E. G. Cf. 1949 *The Badger*, Collins, London.

Pitcher, Dr. R. S. To appear in *J. Horticultural Science*.

Slifer, Dr. Eleanor H. Cf. 1937 *Q.J. Micr. Sci.*, **79**. 493–512 ; 1938 *Q.J. Micr. Sci.*, **80**, 437–537 ; 1946 *J. Exp. Zool.*, **102**, 333–356 ; 1948 *Science*, **107**, 152 ; 1948 *Discuss. Faraday Soc.*, **3**, 182–7 ; 1949 *J. Exp. Zool.*, **110**, 183–203 ; 1949 *Ann. Ent. Soc. Amer.*, **42**, 134–140 ; 1950 *J. Morph.*, **87**, 239–273.

Sutton, Miss M. Expected to appear in *Proc. Zool. Soc.*

Uvarov, Dr. B. P. Cf. 1947 *Nature*, **160**, 857 ; *Report of Fifth Commonwealth Entomological Conference*, Dec. 1948 ; 1950 *Corona*, **2**, No. 5.

Waloff, Miss Z. Cf. 1946 *Proc. Roy. Entomol. Soc. Lond.*, **21**, 81 ; 1948 *J. Anim. Ecol.* **17**, 101–112.

Water conservation in terrestrial arthropods, 1950 *Nature*, **166**, 809.

Section E

Edwards, Prof. K. C. To appear in *Town Planning Review*. Cf. 'Influence of mineral production upon town development in the E. Midlands,' to appear in *Comptes Rendus of International Geographic Congress*, 1949.

Jarrett, H. R. To appear in *Scot. Geog. Mag.* Cf. 'Major natural regions of the Gambia,' *Scot. Geog. Mag.*, Dec. 1949 ; 'The strange farmers of the Gambia,' *Geog. Rev.*, Oct. 1949.

Pre-glacial evolution of the British land surface, 1950 *Nature*, **166**, 757.

Steel, R. W. Expected to appear in part in *Scot. Geog. Mag.* and, expanded, in *Geographical Essays on British Tropical Lands* to be published by George Philip. Cf. 1948 *Geog. J.*, **112**, 64–77 ; 1949 *Trans. Inst. of Brit. Geog.*, 1948, 29–42.

Sweeting, Dr. M. M. Expected to appear in *Trans. Inst. Brit. Geog.*

Thorpe, H. Expected to appear in *Collections for a History of Staffordshire*, edited by Staffordshire Record Society.

Wise, M. J. Cf. 'Growth of Birmingham,' 1950 *Birmingham and its Regional Setting*, B.A., London.

Section F

Fenelon, Dr. K. G. *Ministry of Food Bulletin*, Sept. 9, 16, 1950. Cf. 'Britain's Food Supplies,' 1950 *Adv. of Science*, **24**, 311 ; 'Measuring Britain's Food,' 1949 *Economics*, **1**, Part 1.

Marriner, Miss S. Expected to appear in *Economic History Review*.

Section G

A narrative of the meetings of the Engineering Section is contained in issues of *Engineering* between Sept. 22 and Nov. 10, 1950.

Bowden, Dr. A. T. *Engineer*, Sept. 29, 1950 ; *Engineering*, Sept. 8, 1950.

Cashmore, W. H. *Engineering*, Oct. 27, 1950.

Clarke, Dr. J. S. *Engineering*, Sept. 15, 1950.

Cole, Dr. B. N. *Engineering*, Sept. 29, Nov. 3, 1950.

Desmond, Dr. D. J. *Engineering*, Oct. 20, 1950. Cf. ' The reciprate method of time study analysis,' *J. Inst. Prod. Engineers*, Jan. 1951.

Flint, Dr. A. R. *Engineering*, Dec. 22, 1950.

Gracie, J. J. *Engineering*, Dec. 29, 1950.

Harding, H. J. B., and Golder, Dr. H. Q. *Engineering*, Nov. 24, 1950.

Henderson, J. G. To appear in *Engineering*.

M'Ewen, Prof. E. *Engineer*, Sept. 22, 1950.

Matthew, Prof. T. U. *Engineering*, Dec. 8, 1950.

Parr, G. *Engineering*, Sept. 29, 1950.

Presentation of technical information, 1950 *Nature*, **166,** 500 ; *Engineer*, Sept. 29, 1950 ; *Engineering*, Sept. 8, 15, 22 and 29, 1950.

Russell, A. E. *Engineering*, Sept. 22, 1950.

Saunders, Prof. O. A. *Engineering*, Oct. 6, 1950.

Tustin, Prof. A. *Engineering*, Nov. 10, 1950.

Vernon, Miss M. D. *Engineering*, Sept. 8, 1950. Cf. ' Learning from graphical material,' 1946 *Brit. J. Psych.*, **36,** 145–158 ; ' Visual presentation of factual data,' 1950 *Brit. J. Ed. Psych.*, **20,** Pt. 3 ; ' Learning and understanding,' 1951 *Q. J. Exptl. Psych.*, **3,** Pt. 1.

West, W. J. *Engineering*, Nov. 17, 1950.

Woollard, F. G. *Engineering*, Nov. 3, 24, 1950.

Section H

Barnes, J. A. To appear in *Human Problems in British Central Africa* (*Rhodes-Livingstone Journal*), June 1951.

Concept of culture, 1950 *Nature*, **166,** 711.

Cranstone, B. A. L. To appear in *Man*.

Development of man's use of power, 1950 *Nature*, **166,** 636.

Fussell, G. E. Cf. 1949 *The English Rural Labourer from Tudor to Victorian Times*, Batchworth Press.

Harden, D. B. *Archaeological News Letter*, Jan. 1951.

Seaby, W. A. *Archaeological News Letter*, Dec. 1950.

Section I

Bendall, Dr. J. R. Expected to appear in *J. Physiol.* Cf. ' Factors determining the time course of *rigor mortis*,' 1949 *J. Physiol.*, **110,** 47.

Bullough, Dr. W. S. Parts will appear in *Nature*, *J. Exp. Biol.*, and *Brit. J. Cancer*. Cf. 1948 *Proc. Roy. Soc.*, B, **135,** 212 ; 1949 *J. Exp. Biol.*, **26,** 83 ; 1950 *Brit. J. Exp. Path.*, **31,** 175 ; 1950 *Exp. Cell Research*, **1,** 497 ; 1950 *J. Endocrinol.*, **6,** 340 ; 1950 *Acta Endocrinol.*, **4,** 291.

Chemistry of muscular contraction, 1950 *Nature*, **166,** 591.

Darcus, Dr. H. D. Part to appear in *J. Anat.*

Floyd, W. F., and Silver, P. H. S. Cf. ' Electromyographic study of activity of the anterior abdominal wall muscles in man,' 1950 *J. Anat.*, **84,** 132 ; ' Electromyographic study of standing in man,' 1950 *J. Physiol.*, **111,** 5P ; ' Electromyographic study of standing in man, thigh and leg muscles,' 1950 *Ibid.*, **111,** 22P.

Functions of the skin of vertebrates, 1950 *Nature*, **166,** 672.

Hormones of the digestive tract, 1950 *Nature*, **166,** 714.

Medawar, Prof. P. B. Cf. ' Recent work on the biology of skin,' 1949 *British Science News*, **2,** 148.

Nerve fibre, 1950 *Nature*, **166,** 713.

Perry, Dr. S. V. To appear in *Biochem. J.* Cf. 1950 *Biochem. J.*, **47,** 38.

Weiner, Dr. J. S. Expected to appear in M.R.C. Report of a symposium on the application of scientific methods to industrial problems. Cf. ' Lactic acid and sweat glands function,' 1949 *Nature*, **164,** 351 ; ' Composition of arm and general body sweat,' *J. Physiol.*

Section J

Baldamus, Dr. W. To appear in *Brit. J. Sociology*.

Flood, Dr. W. E. 1950 *Nature*, **166,** 592. Cf. ' Peoples particular interests in science,' 1948 *Adult Education*, **21,** No. 2 ; ' Viewpoints and approaches in popular science,' 1949 *Adult Education*, **22,** No. 2.

Hughes, E. W. *Colliery Guardian*, Nov. 9, 1950.

Katz, Prof. D. To appear in *Revue Internationale de Filmologie*.

Marriott, R. To appear in *Occupational Psychology*. Cf. ' Size of working group and output,' 1949 *Occupational Psychology*, **23,** 1, 47–57.

Meredith, Prof. G. P. Cf. ' A revision of Spearman's Noëgenetic Principles,' *Proc. Aristotelian Soc.*, March 7, 1949 ; ' The analysis of relations,' *Proc. Leeds Phil. Soc.*, Dec. 1949 ; ' Topic analysis,' *Researches and Studies, U. of Leeds Inst. of Education*, Dec. 1949 ; ' Transfer of training through topic analysis,' *Researches and Studies, U. of Leeds Inst. of Education*, May 1950.

Smith, P. To appear in *Occupational Psychology*.

Socio-psychological factors in productivity, 1950 *Nature*, **166**, 638.

Stansfield, R. G. Expected to appear in *Occupational Psychology*.

Trenaman, J. Summary in 1950 *Nature*, **166**, 814. Part in *Adult Education*, Dec. 1950, part in *Q. J. of Speech*, U.S.A., Dec. 1950.

Valentine, Prof. C. W. Cf. 1947 *Psychology of early childhood*, Methuen, London; 1948 *The difficult child and the problem of discipline*, Methuen, London; 1950 *Psychology and its bearing on education*, Methuen, London.

Vernon, Mrs. D. F., and Prof. P. E. Summary in 1950 *Nature*, **166**, 814. To appear in *B.B.C. Quarterly*, Jan. 1951.

Section K

Bond, Dr. G. To appear in *Ann. Bot.*, Vol. 15.

Chemistry of the cell with special reference to the nucleus, 1950 *Nature*, **166**, 771.

Climatic limits of vegetation, 1950 *Nature*, **166**, 536

Cooper, J. P. Expected to appear in *J. Ecol.*, July 1951. Cf. 'Daylength and head formation in rye grasses,' 1950 *J. Brit. Grassland Soc.*, **5**, 105–112; 'Studies on growth and development in *Lolium*,' 1949 *J. Ecol.*, **37**, 233–259.

Cour, L. F. La. To appear in *Heredity*. Cf. 'Nucleic acid starvation of chromosomes in *Trillium*,' 1940 *J. Genet.*, **40**, 185–217; 'The detection of inert genes,' 1941 *J. Hered.*, **32**, 115–121.

Cytology and genetics in relation to the classification of plants and animals, 1950 *Nature*, **166**, 769.

Forestry in water catchment areas, 1950 *Nature*, **166**, 584.

Janaki-Ammal, Dr. E. K. *Rhododendron Society's Year Book, 1950*.

Larsen, Dr. C. S. To appear in *Forestry*. Cf. 'Estimation of the genotype in forest trees,' *Royal Veterinary and Agricultural College Yearbook, 1947*.

Learmonth, A. T. A. Cf. 'Floods of August 12, 1948, in S.E. Scotland,' 1950 *Scot. Geog. Mag.*, **66**, No. 3.

Leslie, I. Cf. 'A new approach in the biochemistry of growth and development,' 1950 *Nature*, **165**, 49–53; 'Nucleic acids in relation to tissue growth,' 1950 *Cancer Research*, **10**, 587–94.

Macdonald, J. To appear in *Q. J. of Forestry*.

Newton, R. W. B. To appear in *Roy. Forestry Soc. J.*

Overend, Dr. W. G. Cf. 1949 *J. Chem. Soc.*, 1222; 1949 *Ibid.*, 2836; 1950 *Ibid.*, 1027; 1950 *Ibid.*, 2769; 1949 *Nature*, **163**, 538; 1950 *Ibid.*, **166**, 771.

Present position of the theory of continental drift, 1950 *Nature*, **166**, 585.

Prothero, R. M. Cf. 'Factors affecting land-use in the Taf Fechan Valley, Breconshire,' 1949 *J. Brit. Grassland Soc.*, **4**, No. 3.

Rees, Dr. W. J. Expected to appear in *J. Ecol.*

Rehabilitation of derelict areas, 1950 *Nature*, **166**, 630.

Singh, Dr. B. N. Cf. 1950 *Nature*, **165**, 65.

Stern, Col. F. C. Cf. 1949 *Proc. Linnean Soc. Sess.*, **161**, Pt. 2.

Section L

Birley, Dr. R. *Education*, Oct. 20, 1950.

Section M

Davies, Dr. W. Expected to appear in *J. Brit. Grassland Soc.*

Quality in grassland, 1950 *Nature*, **166**, 760.

Wain, Prof. R. L. To appear in *J. Sci. of Food and Agriculture*.

Watson, Sir James Scott. *Farmers' Weekly*, Sept. 7, 1950.

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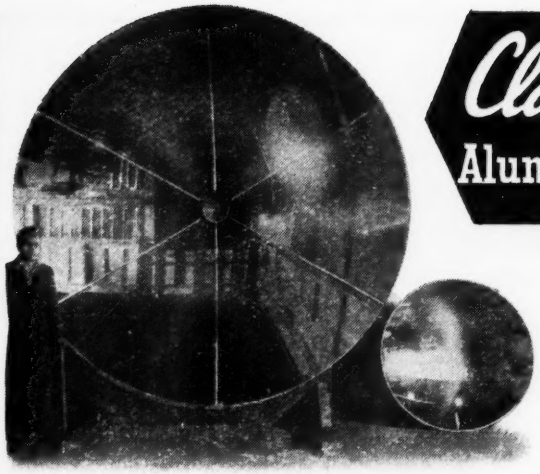

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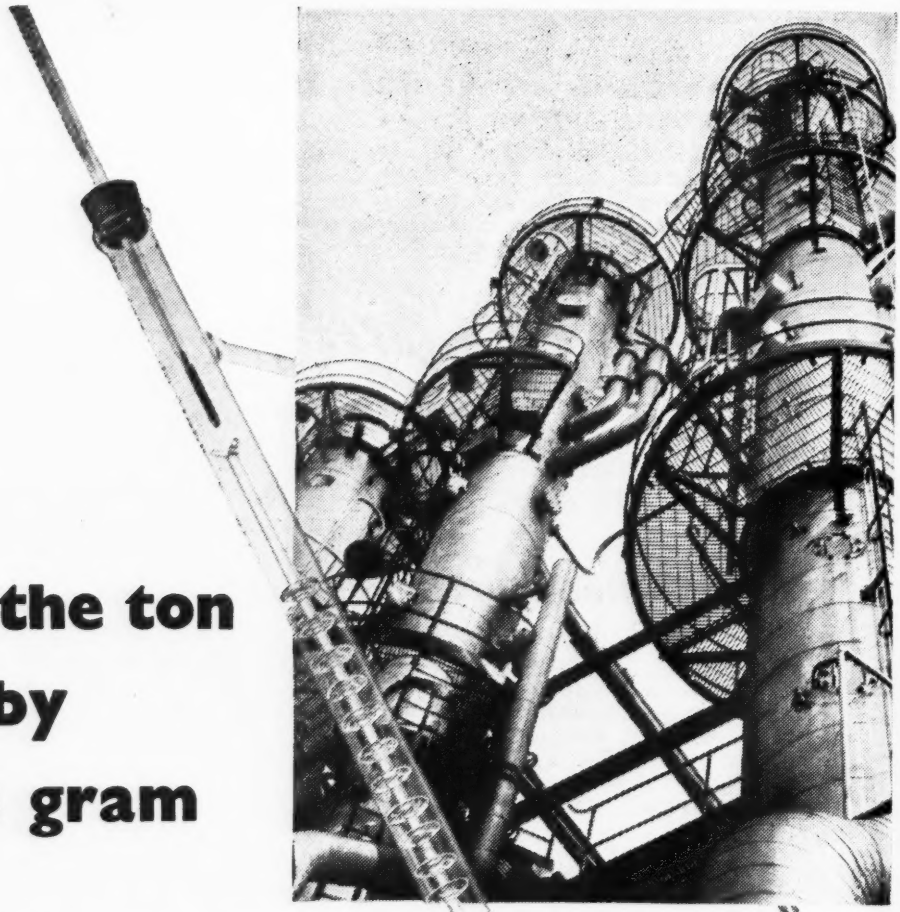

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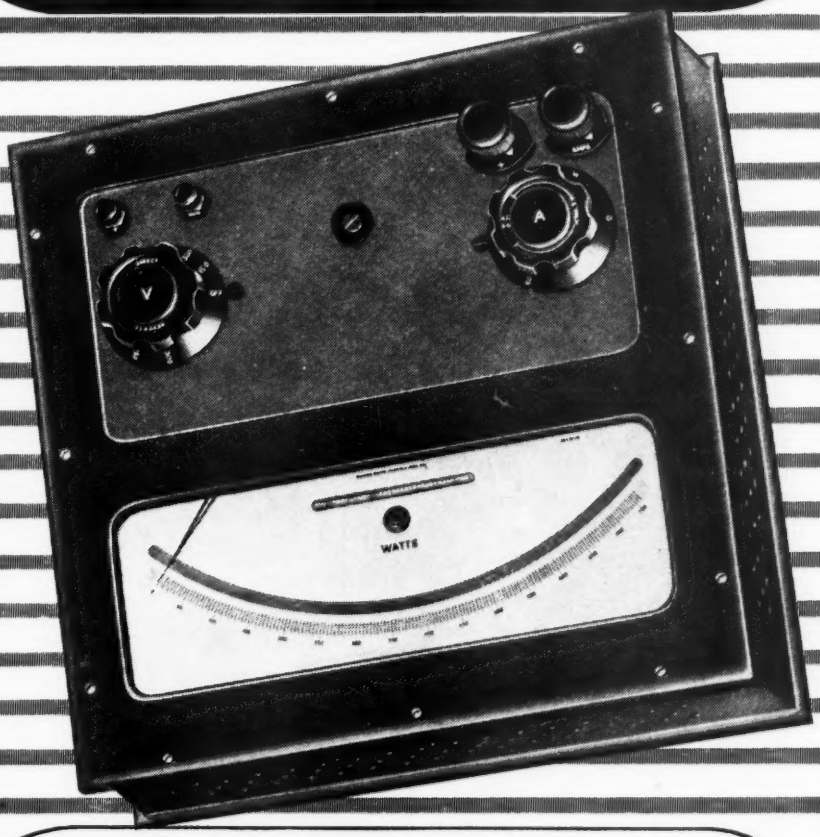

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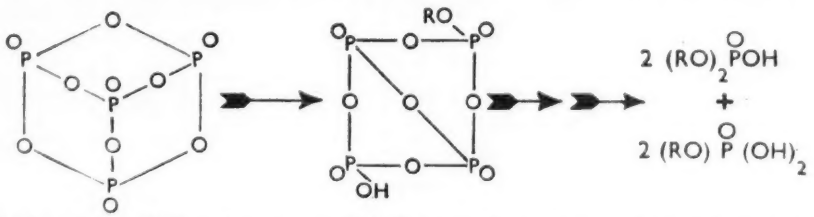

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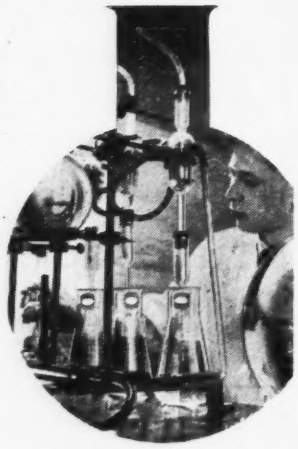

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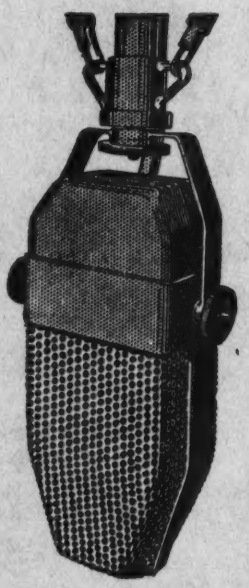

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